The Institute of Physics

BULLETIN

FEBRUARY 1957 · VOL. 8 · No. 2

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The Bulletin is published by The Institute of Physics for circulation to its members.

Notices to Members

Payment of Subscriptions

The Treasurer wishes to thank the many members who responded promptly to his reminder that annual fees were due, which was included with the January *Bulletin*. (This did not, of course, apply to those who pay by standing Banker's Order.) He hopes that any who overlooked this reminder will deal with it as soon as possible ; duplicate copies of the form will be sent on request.

Oxford Convention

The attention of members is drawn to the details of the Oxford Convention given on the outside back cover. Programs and forms of application will be circulated with the March *Bulletin*. It is hoped that there will be a very large attendance ; the convention is confined to members, their ladies and, if accommodation should permit, other guests personally introduced by members who are themselves attending.

Radiofrequency Spectroscopy Symposium

The Committee which was appointed at the symposium held in Bangor last September under the auspices of the Liverpool and North Wales Branch announces that it is arranging for the next symposium to be held in the University of Southampton from September 19–21. The meeting will be mainly concerned with investigations by electron resonance techniques. Further details will be announced later, and will be available from Dr. D. J. E. Ingram, The University, Southampton.

Investigating the Structure of the Atomic Nucleus, 1919-1956*

By Professor S. DEVONS, M.A., Ph.D., F.R.S.

(*University of Manchester*)

THIRTY-SEVEN years ago, here in Manchester, in these laboratories, the disintegration of the nucleus of the nitrogen atom was demonstrated by Rutherford, and with this remarkable achievement the subject of nuclear physics was full born. Previous to this event the manifestations of the atomic nucleus as a complex structure were limited to the special phenomena of natural radioactivity, and, in so far as nuclear and atomic phenomena were distinguishable in terms of the Rutherford-Bohr atomic model, the nuclei of the great majority of atoms were simply heavy, charged, "point" particles whose structure played no role in contemporary physical science. With the limited and incredibly simple resources at his disposal Rutherford was only able to observe transmutations of the nuclei of the lighter elements, and although the gap between the artificial disintegration of the light nuclei and the spontaneous disintegration of the heavy, radioactive nuclei was not bridged until many years later, Rutherford's experiments not only clearly indicated the essentially complex structure of all atomic nuclei but also demonstrated how such structure could be explored.

Since 1919 the study of the atomic nucleus has grown into a vast field of physics. Innumerable experimental measurements of nuclear phenomena have been made, and a great number of new methods have been devised for studying nuclear properties. Nuclei, and nuclear particles, have been bombarded in a large variety of ways, and processes described as scattering, excitation, disintegration, capture, synthesis, evaporation, splintering, fission, and spallation, have been observed and measured. An extensive array of new radioactive nuclei, ranging in mass from the lightest to the heaviest nuclei, have been made artificially, and the hundreds of isotopes which comprised the stable nuclei have been separated, identified, and weighed. Gaps in the chemical periodic table of the elements have been filled by new radioactive elements, and, what is perhaps most dramatic of all, the natural boundary to the range of chemical elements at atomic number 92 (uranium) has been traversed and some ten new "man-made" elements have, so far, been added to the list of elements. And not only have these new nuclei been produced in quantities sufficient to identify them and measure their properties, but the amounts in which some of them have been produced must by now be measured in tons!

Many of these nuclei, the radioactive as well as the stable ones, have been produced and examined in excited states, and we now have extensive knowledge of their spectra of γ-radiations and energy levels comparable in scope with our knowledge of atomic spectra, as well as detailed measurements of the lifetimes, β-spectra, and α-particle spectra, of the radioactive nuclei. By less vigorous and more subtle procedures, the precession of many of these nuclei, mostly the stable ones, in electric and magnetic fields, has been measured with fantastic precision, thereby providing measurements

* A lecture given to the Manchester and District Branch on February 10, 1956.

of nuclear mechanical, magnetic, and electric moments. At the other end of the scale, using particles, from both cosmic radiation and accelerating machines, of energies far surpassing the energy of the particles for radioactive nuclei, new nuclear particles, or indeed we might say new forms of matter, have been identified and produced artificially.

To-day, our familiarity with the behaviour and structure of atomic nuclei is sufficient that we can talk about, with some confidence, not only nuclear charge and mass, but the size, shape, angular momentum, charge distribution, and magnetic moment of the nucleus. We can investigate the dynamical properties of the nucleus in considerable detail, and such concepts as nuclear deformation, compressibility, surface energy, surface oscillation, and rotation, as well as the thermodynamic properties of temperature and entropy, can all be applied with some measure of significance.

This great advance in our detailed knowledge and understanding of nuclear properties has been made possible by an unparalleled development in experimental technique. The most striking advances of all have taken place in the development of machines for particle acceleration. Rutherford used the α-particles of naturally radioactive materials with energies of a few million electron volts, sufficient to overcome the electrostatic repulsion of the nuclei of the lightest elements. Particles of this sort of energy still provide the commonest, and very useful, means of exploring nuclear properties, but during the past 25 years or so, since the " machine-age " of nuclear physics was inaugurated by Cockcroft and Walton, accelerating machines of steadily increasing size have replaced natural sources as a means of providing particle beams. These machines now provide intense beams of canalized nuclear particles of many types with a wide range of energies which can be controlled with great precision, and with such beams a wide range of refined and accurate nuclear measurements can be made.

For many of the most detailed and precise studies of nuclear structure and nuclear dynamics, the modern electrostatic generator, pioneered by Van de Graaff, provides to-day a most versatile and reliable tool. Its particular features are the high degree of energy homogeneity and the readily variable energy of the particle beams produced, and although the largest machines of this type are limited to a voltage of about 10 MeV, this is sufficient for the investigation of a wide range of nuclei and nuclear processes. For still higher energies, or where flexibility and precision are of less importance, for example in the production of new radioactive nuclei, the cyclotron invented by Lawrence has been, and still is, one of the most widely used tools.

The past decade has seen the intensive development of much larger, higher energy, machines, producing nuclear particles with energies ranging up to a thousand times the few million electron volts necessary to surmount the nuclear potential barrier. These machines have been used not so much to study the details of nuclear structure as to investigate the properties of the nuclear constituents, the nucleons themselves. One might also mention the electron-accelerating machines, betatrons, synchrotrons, and linear-accelerators, producing electrons and X-rays of hundreds of millions of electron volts, which have proved invaluable in the study of high-energy electromagnetic processes such as nuclear photo-disintegration and electron scattering.

Apart from accelerating machines which provide beams of charged particles, the other great line of development has been in the production of intense fluxes of neutrons, and in particular slow neutrons, by means of nuclear reactors. Although, of course, the discovery of the neutron and the investigation of its interaction with atomic nuclei played a paramount role in the development of nuclear physics, at the present time the use of neutron beams from nuclear reactors as a means of studying nuclear structure is limited to certain special types of problem. For many nuclear investigations, neutrons of more homogeneous energy, which can be controlled more readily, are obtained

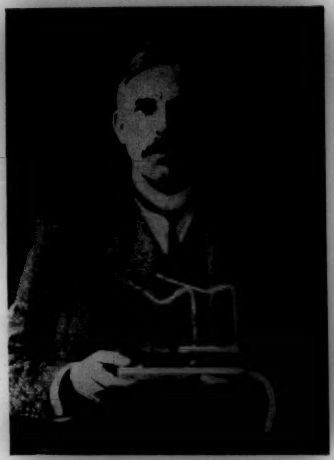

FIG. 1. *Rutherford with his apparatus, 1919.*

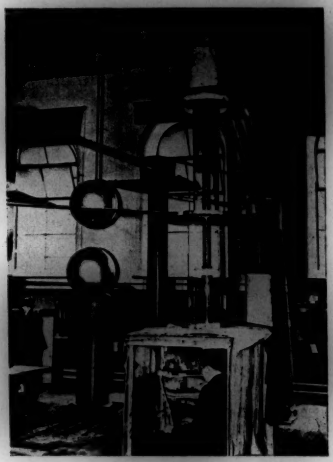

FIG. 2. *Cockcroft and Walton's equipment, 1932.*

indirectly from nuclear reactions induced by artificially accelerated charged particles.

The change in the physical scale and complexity of the apparatus of nuclear physics hardly needs emphasis. Rutherford was able to carry the whole of this apparatus in his hands, and even allowing for the fact that Rutherford was a big man in every sense of the word, the famous photograph shows how small and simple indeed was the apparatus he used.

How different already was the "home-made" equipment of Cockcroft and Walton, and the contrast between this and the large-scale precision engineering of contemporary equipment is almost as great.

In parallel with the development of accelerating machines, there has been a comparable, although less spectacular, development in the technique of detecting and recording nuclear particles and radiations. Some of the earliest techniques, such as the Wilson cloud-chamber, the Geiger counter, and the zinc-sulphide scintillation screen, are still employed, dressed up in a modern engineered form. Indeed most of the modern techniques, including the two in widest use to-day, the photographic emulsion and the scintillation detector, are refinements and extensions of the methods known and used fifty years ago. Combined with elaborate electronic techniques for amplifying, analysing, and recording at very high speed the primary detector signals, the scintillation counter especially has become a most powerful means of detecting, identifying, and simultaneously measuring the energy of different types of particle and γ-radiation. For accurate quantitative measurements of large numbers of particles, where the qualitative features of the nuclear process under investigation are well understood, it is of unrivalled value. On the other hand, for obtaining a comprehensive and compact picture, quantitative as well as qualitative, of individual, complicated, and particularly unfamiliar nuclear processes, the photographic emulsion and the cloud chamber enable an extra-ordinarily large amount of information to be recorded in a

direct and simple fashion. Put briefly, the photographic emulsion and cloud chamber enable complicated events in the three space dimensions to be recorded ; the high speed counters are supreme in the fourth dimension, time.

With the elaborate techniques of particle acceleration and detection, a great many precision experiments have been made possible. Accurate measurements of the cross-sections for nuclear processes, and their variation with angle and energy together with high resolution spectrometry of the radiations and particles produced are now commonplace. The powerful coincidence technique allows one to study the correlations between radiations emitted successively, a type of measurement which has been exceptionally fruitful in the analysis of the β- and γ-spectra of nuclei in terms of the spectra and properties of nuclear levels. There has also been a great development in the application of quantum mechanics to the interpretation of experimental results in terms of nuclear properties. Quite apart from any comprehensive theory of nuclear structure, theoretical analysis now plays an important role in allowing one to extract from the primary empirical information the essential nuclear properties which the measurements reveal. To-day, when a good many of the qualitative and quantitative features of nuclear structure and nuclear reactions are well understood, or at least quite familiar, experimental empiricism has largely given way to sophisticated, quantitative experiments designed to investigate some particular aspect of nuclear structure or nuclear dynamics, and requiring for their interpretation an extensive background of quantum-mechanical theory. From a theoretical point of view this primary analysis of experimental observations represents the first step towards a full theory of nuclear processes. Before discussing the extent to which such a theory exists, let us look at the general features of the picture we now have of atomic nuclei.

We know the size of nuclei with considerable precision. The surface of a nucleus is fairly sharply defined and the mean radius of this surface, $1{\cdot}2 \times 10^{-13} \times A^{\frac{1}{3}}$ cm. (A is the nuclear mass, i.e. the number of constituent nucleons) is now well established. Recent experiments have even measured the "thickness" of the surface layer ($\sim 10^{-13}$ cm.), which represents the intermediate region where the density of the nucleus falls from its average, approximately constant value in the interior to a negligible value outside the extreme boundary. We have also strong evidence that nuclei differ in shape, as well as size, being most nearly spherical when the numbers of constituent neutrons and protons are near to the numbers required to form a "closed-shell," and conversely there are the maximum departures from sphericity when there is a large excess (or deficiency) of neutrons or protons over and above the number required for closed shells.

These variations of size and shape are, however, all consistent with a density of nuclear matter which is approximately the same for all nuclei from the lightest to the heaviest. (This is, of course, in marked contrast to atomic structure : the size of all atoms is very roughly the same but their masses vary over a wide range.) Since also all nuclei have approximately the same composition (roughly equal numbers of protons and neutrons with a small excess of the latter), there is some significance in talking about a typical sort of nuclear material. Quantitatively such a material is very different from any macroscopic form of matter ; for example the difference between this material and a dense solid is far greater than that between a dense solid and gas at N.T.P.

	Nuclear Matter	*Dense Solid*	*Gas at N.T.P.*
Density (gm/cm^3)	$2{\cdot}10^{14}$	20	10^{-3}
Surface Energy (ergs/cm^2)	10^{20}	100	—
Compressibility (dynes/cm^2)	10^{33}	10^{12}	10^{6}

Not only is nuclear matter quantitatively very different from ordinary macroscopic forms of matter, but qualitatively there are

also fundamental differences which are of great importance, particularly for the understanding of the properties of individual nuclei. Although there is some significance in talking of the average properties of nuclear matter, as if individual nuclei formed a small part of a material that could exist to an indefinite extent, in the study of real nuclei we are not allowed to forget for long the fact that we are dealing with an aggregate of a finite number, A, of particles, neutrons and protons, ranging from unity to say 250. Moreover, all these A nucleons are particles of equal size and mass, and except for the secondary effects of their electric charges, must be treated on an equal footing. Again we can contrast this situation with that in other branches of physics. For example, in dealing with the physics of solids we have assemblies of closely interacting similar particles, atoms and electrons, but the constituent number of such particles is very large indeed. In atomic physics we again have many interacting particles—electrons and nucleus, but here one particle, the nucleus, plays a dominant role, a feature which enables us effectively, if only approximately, to reduce the problem to a two-body problem of much less complexity.

In another major respect the physics of nuclear structure differs from that of other physical systems : the forces between nucleons have no macroscopic counterpart (at least in any conditions in which measurements might feasibly be made !). They are short-range forces which can only be studied by investigation of the interaction of individual nucleons with each other, or by the study of actual complex nuclei, when two problems, that of nuclear forces and of nuclear structure, have to be dealt with simultaneously. A very good picture has been obtained of the magnitude, range, and general properties of nuclear forces by studying such simple systems as a single neutron and proton (neutron-proton scattering and the properties of the stable deuteron), or two protons (proton-proton scattering), over a wide range of energies. The picture of nuclear forces provided by such measurements, supplemented by some inferences from the study of more complex nuclear systems, goes a long way to explain the *general* features of nuclear structure, but we cannot be sure that some of the details of nuclear behaviour may not be related to unknown aspects of these forces.

In one respect the study of nuclear structure is on a par with the study of other microscopic phenomena : the basic principles of quantum mechanics appear to be applicable and valid. Some novel features have naturally arisen in the application of quantum mechanics to nuclear problems, particularly in relation to the fact that nuclei comprise two sorts of particle, proton and neutron, whose properties are very similar in most respects, i.e. the essentially nuclear forces are the same for any pair of nucleons, although these may differ in their electromagnetic properties. For processes involving only moderate energies (a few MeV or less), the classical approximation to the description of nuclear processes is not a reasonable approximation. Quite generally nuclei in their normal stable state, and in states of low excitation, are highly " degenerate " from the quantum-mechanical point of view ; that is to say, they are systems with zero-point energy which is large in comparison with their " thermal " energy. In this respect they probably bear more resemblance to macroscopic matter at very low temperatures, exhibiting such properties as the superfluidity of liquid helium and superconductivity, rather than to materials at ordinary " high " temperatures.

Here again one must emphasize the distinctive feature of actual nuclei, that they are composed of a relatively small number of particles, as compared with the number of atoms and electrons in even the smallest superfluid system. However, whatever may be the difficulties in applying quantum mechanics, including the possibility that the theoretical techniques developed so far may prove inadequate, there is no hint as yet that there is anything essentially incorrect in the application of quantum mechanics to the systems of nuclear dimensions. Indeed the range of phenomena which can be explained in terms of the same principles is

most impressive. For example, in the interaction of nuclei with the electromagnetic field, we have the same basis of quantum-electrodynamics whether we deal with transitions of the nucleus as a whole in the radio frequency spectrum region of some 10^8 cycles/sec. (corresponding to 10^{-7} eV), or the "giant resonances" for the nuclear photon effect at a γ-energy of some 20 MeV (frequency of 2×10^{22} cycles/sec), a range of 10^{14} : 1.

A system of closely interacting particles has many degrees of freedom ; the extent to which they are excited depends on the mode, and particularly on the energy, of excitation. For example, whilst some types of nuclear processes can be interpreted in terms of the excitation of one or two nucleons with the remaining part of the nucleus playing a relatively passive role, there are others in which the essentially average or collective properties of the whole nucleus appear to give the most appropriate description. An example of the first type would be a γ-transition between two nuclear states of low energy, where the difference between the two states can, in many cases, be interpreted in terms of the change in the state of one, or a very small number, of the constituent nucleons. Such a characterization of the individual nuclear states forms the basis of the remarkably successful nuclear shell model, which is very similar in principle to the shell model of atomic structure. On the other hand, in the interaction of a nucleon with an energy of a few MeV or more, the whole nucleus can be represented as a region of nuclear dimensions with complex refractive index ("clouded crystal ball" model), and this provides a surprisingly good explanation of the observed features of the scattering of nucleons by nuclei of all sizes. In this latter case the whole aggregate of nuclear particles is represented by three physical magnitudes : the real and imaginary parts of the refractive index and the nuclear radius. The fission of a heavy nucleus into two small parts is another quite different example of a process which, since it involves a rearrangement of all the nucleons, is difficult to interpret in terms of the detailed motions of the individual particles, but whose main features can be understood in terms of a much less detailed collective model, in which such concepts as surface oscillation and surface energy play a prominent part.

In recent years considerable success has been achieved, particularly by A. Bohr and his collaborators, in studying the interrelation between these two sorts of degrees of freedom, collective and individual particle, but both are introduced separately on a rather *ad-hoc* basis. Yet clearly these two types of description of the motions of nucleons in a nucleus are but two aspects of the same thing, and in principle a *complete* description in terms of the individual, but correlated, nucleon motions would also include the "collective" degrees of freedom. This is not, in some respects, a new sort of physical problem. The relation between the motions of the individual atoms in a crystal and the vibrations of the lattice, or between, say, the polarizability of an atom or molecule and the discrete energy levels of such systems as are manifested in their spectra, represent similar physical situations. But in the case of the nucleus, with its finite number of similar, closely interacting particles, we are yet some way from a comprehensive theory into which these different aspects of nuclear behaviour can be fitted.

We do know, from many experiments, that the behaviour of nuclei can be remarkably simple as well as very complicated. These simple features do suggest that in the appropriate circumstances the complex aggregate of particles can exhibit simple forms of motion which can be associated with particular degrees of freedom. Sometimes the agreement between theory, based on a simplifying model, and experiment is far better than could justifiably have been expected. One of the outstanding problems is how, starting with the known constituents and the extensive knowledge of the forces between them, we can demonstrate that these particularly simple (or at least apparently so) forms of behaviour should be expected. For example, we might well enquire to what extent the observed behavour is a

consequence of the fact that motions of the nuclear constituents, the neutrons and protons, is governed by the exclusion principle, or to what extent it is due to some feature of nuclear forces. Some progress in devising theoretical techniques for dealing with such a problem has been made in recent years by K. A. Brueckner and his collaborators, but a detailed comprehensive theory able to deal with the great variety of nuclear phenomena still seems a long way off.

What types of experiment and measurement are now likely to be of value in obtaining a more penetrating picture of nuclear structure ? Do we need a more fundamental understanding of the nature of nuclear forces, and does this in turn mean the construction of still larger machines to reach still higher energies ? We may recall that in his classic investigation of *atomic* structure Rutherford used particles of far greater energy than the typical energies of the electrons in the atom, and so obtained a simple, direct picture of the atom. Is the situation likely to be similar in the case of the nucleus ? The typical average energy, kinetic and potential, of nucleons in the nucleus is only some few tens of MeV, so that most types of nuclear excitation require only modest energies ; but perhaps to reveal some of the deeper or finer features we shall need particles with energies of hundreds of MeV whose De Broglie wavelength is not large compared with the average separation of nucleons inside the nucleus. However, we should also remember that many of the features of atomic structure, and particularly some of the finer details, have been inferred from the study of atomic spectra, once a correct general model was discovered ; and similarly precise and sophisticated experimental measurements of low energy nuclear phenomena may enable us to infer even the profoundest features without having to use the more direct information supplied by the use of high energy particles.

As far as the investigation of the basic nuclear forces is concerned, the use of particles of very high energy seems to lead as much to the creation of new problems (and particles !) as to the solution of existing ones. Many of the measurements of the interaction of high energy nucleons have, however, provided valuable information about nuclear forces which is relevant to the behaviour of nucleons inside the nucleus and the general problems of nuclear structure. For example the recent measurements of the polarization of *high energy* nucleons scattered by nuclei is closely related to the " spin-orbit " interaction which plays a key role in the shell model of the nucleus, a model which finds its main application in the description of the properties of nuclei in their *lowest energy* states. Again detailed studies of the nuclear scattering of electrons with energies up to several hundred MeV have provided accurate estimates of the extent and distribution of charge inside the nucleus (and even in the proton itself), results which are of great importance in interpreting the " static " and low-energy properties of nuclei. At still higher energies studies of the interaction between individual nucleons, and between nucleons and mesons, have confirmed the essential similarity of neutron and proton and basic charge-symmetry of nuclear forces.

But the variety and complexity of the phenomena at the highest energies hardly seem in keeping with the aim of obtaining a more direct and simpler interpretation of nuclear structure. The construction of machines for still higher energies is more likely to be governed by the limitations of human skill and resources than by their direct relevance to the problem of nuclear structure. Yet we might, finally, remember that with one and the same tool, the α-particles from radium, Rutherford was able to demonstrate the essential simplicity of the atom and the complexity of the atomic nucleus. It may be that the machines producing the high-energy particles of to-day and tomorrow provide the means to demonstrate the essential simplicity of the nucleus as well as the complexity of the nucleon. History may be repeating itself.

New Year Honours List

Members will have noted with special pleasure the announcement in the New Year Honours List of the conferment upon Sir John Cockcroft (*Immediate Past President*) of the Order of Merit. Membership of this Order is limited in number to twenty-four and is widely regarded as the highest public recognition of outstanding eminence in literature, science, the arts or public service. Sir John is the fifth Past President of the Institute to be honoured with this award, the others being Sir Joseph Thomson, Sir Charles Parsons, Sir William Bragg and Lord Rutherford.

Awards to the President and four other Fellows were also included in the Honours List as follows :—

Knighthood :	Professor L. H. Martin
C.B.E. :	Mr. O. W. Humphreys
	Dr. A. T. Green
	Professor W. V. Mayneord
O.B.E. :	Mr. H. Kronberger

The warm congratulations of the Board, on behalf of members, have been expressed to these Fellows on the public recognition of their work.

Reviews of Books

THE GRAMOPHONE HANDBOOK

By Percy Wilson

London : Methuen & Co. Ltd. Pp. 227 + xlii. Price 15s.

In this book the Technical Editor of *The Gramophone* provides an up-to-date survey of modern developments in the reproduction of sound. Though intended for the ordinary reader, the book achieves its object rather by clarity and conciseness of exposition than by avoiding all but the simplest technicalities ; indeed it manages to convey a vast amount of exact information of the kind that users of the various forms of recording and reproducing apparatus constantly stand in need of, but which is not otherwise readily available. In every sense of the term it fulfils all that one demands of a handbook.

After preliminary chapters on the nature of sound, and the general principles of recording systems, practical advice is given on pickups and styli, carrying arms and turntables, record wear, surface noise and care of records, amplifiers and control units, loud-speakers and enclosures, high fidelity equipment, tape recorders, together with useful hints on installation and maintenance. The text is admirably displayed and aptly illustrated with 16 half-tone plates and 40 line diagrams. A glossary of some 150 technical terms concludes a volume which can be recommended strongly to music lovers, teachers and all those who are interested in recorded sound.

H. Lowery.

INTRODUCTION TO ELECTRICAL APPLIED PHYSICS

By N. F. Astbury

London : Chapman & Hall Ltd. Pp. 241 + xi. Price 36s.

The book includes ten chapters and these are on a physical introduction to the subject, which includes an elementary and necessarily qualitative account of atomic physics, in relation to such matters as the origin of magnetism, dielectrics, etc., the electric field (electrostatics), the magnetic field (elementary electro-magnetism), electrical

units, both in their own right and in relation to Maxwell's equations, etc., simple circuit theory and networks, lines and attenuators, etc., the magnetic circuit, real circuit components, electro-mechanical and electro-accoustical systems, electron devices and, finally, electro-magnetic waves and radiation.

The scope of the book is somewhat unusual and interesting and it would appear that it is most suitable for physics and electrical engineering undergraduates in their pen-ultimate year. This is intended to mean that students in physics who specialize in electricity in their final year and electrical engineers in their final year would find the scope of the book somewhat limited in that it does not take any of the topics mentioned above to any great length. This is not meant in any critical sense, since unfortunately it is rarely, if ever, that a book is written which covers the entire undergraduate course for physicists or, more particularly, electrical engineers.

MKS units are used and the two chapters dealing with this subject are readable and not as dogmatic as some other treatments of this system.

It is the reviewer's opinion that Chapter 11 on Electronic Devices, which covers some 27 pages, could well have been left out since it is so incomplete and the subjects described therein are adequately dealt with in other textbooks. There seems no reason to dilute what is essentially a book on circuit theory, etc., with an introduction to electron physics or vacuum electronics. The chapter on electro-magnetic waves and radiation serves as a good introduction to a more detailed treatment and follows the vector theory used in early parts of the book. Perhaps one of the most interesting chapters is that on electro-mechanical and electro-acoustical systems since the relation between mechanical and electrical systems (analogues, etc.) is very often not stressed at all in books of this kind, and in view of current interest in transducers, analogue systems, etc., this does seem unfortunate.

The printing and technical production of the book are both excellent.

J. D. CRAGGS.

THE ATOM

By Sir George Thomson

London : Oxford University Press. Pp. 201 + v. Price 7s. 6d. Fifth Edition.

The task of keeping up to date over the last twenty-five years any book about atomic physics, even one written for the non-specialist reader, is truly formidable, and one takes up the fifth edition of Sir George Thomson's "The Atom" curious to discover what will be his solution.

Through the greater part of the book the changes are slight and unobtrusive, and the merits of presentation which have made the earlier editions so valuable remain. Here the present day reader, who may be forgiven if he is sometimes tempted to think of atomic physics as a post-war development, is reminded once more of the classical investigations, unspectacular although they perhaps are when compared with some recent achievements, in which are the true foundations of the subject. Although these lie only fifty years away, we are as dependent for a general record of their development on accounts such as that found in this little book as if they had taken place a thousand years ago. The additions, which carry the story to the last year or two, are necessarily of a very selective character ; nuclear transformations are not treated at all extensively but more attention is given to the ideas of nuclear energy and of the so-called fundamental particles. The presentation here is of the same kind as that familiar in the earlier parts of the book, and the new sections follow these excellently.

This book remains, as it has been in its earlier editions, a first-rate introduction to atoms in their broad application to physics and chemistry. There is one minor shortcoming ; the bibliography would have been the better for much more drastic revision, for as it stands it gives little indication of all that has been written for the non-specialist in the post-war years.

J. G. WILSON.

Vol. 8, February, 1957

Degree and Diploma Courses in Applied Physics

The report of a conference organized jointly by The Institute of Physics and The London and Home Counties Regional Advisory Council for Higher Technological Education, and held on November 15 and 16, 1956, at The Institution of Electrical Engineers, London

FIRST SESSION

Thursday, November 15, at 9.45 a.m.

Chairman : O. W. HUMPHREYS, Esq., C.B.E., M.I.E.E., F.Inst.P.

(*Director in charge of Research, The General Electric Co. Ltd.; President of The Institute of Physics*)

Mr. O. W. Humphreys

It is my privilege and pleasure, on behalf of The London and Home Counties Regional Council for Higher Technological Education and The Institute of Physics, to welcome you all to this conference on Degree and Diploma Courses in Applied Physics. You are, if I may say so, a very representative cross section of suppliers and users of physicists and I am hopeful that our discussions will bring us together in a closer understanding of one another's problems.

The shortage of scientists is no longer news. Much has been said, may be too much, on means of increasing the supply. Little—far too little—has been said—and done—concerning the complementary approach of making the most of the scientists we have.

This is the concern of both the teaching world and industry. This conference is intended to concentrate, as I hope it will, on the educational side of the problem, but this fact in no way belittles industry's responsibility for the further training and proper utilization of its scientific and engineering staffs. That might well be the subject of another conference.

The fact that this conference is being held indicates a recognition, maybe somewhat belated, of the possibility that a course designed for potential research physicists may not completely meet the needs of the man destined to apply his scientific knowledge on the factory floor or in the development laboratory. Lest the pendulum swing too far, however, let us not lose sight of the importance, to every physicist, of a sound foundation of basic physical knowledge.

It is not for me to attempt even the most cursory survey of the field over which our discussions will doubtless range, but there is one subject—very near to my heart—on which I would like to dwell for just a few minutes.

Do you remember how frequently before the war one used to hear criticisms of the time which it took to convert the results of research into production ? Have you heard much talk of this kind in recent years ? I have not and I have been asking myself why this is. It stems, I think, from a revolutionary change in the relationship between research and engineering of which many people may still be unconscious although it has in fact gone a very long way.

It you go back far enough in history you find research the prerogative of the universities and its results not influencing engineering

until absorbed into the engineers' general background of knowledge. Gradually, and with increasing tempo between the wars, the position began to change as industry entered the research field on its own account. It changed for two reasons ; firstly research programs were planned with the needs of industry very much in mind ; secondly the close association between engineers and industrial research workers, coupled with the form in which the research results were presented, led to a more rapid assimilation of the new knowledge by those whose task it was to apply it. But even up to the outbreak of the second world war research and engineering were still regarded as things which should be kept apart lest the one suffered from too close contact with the other. How frequently at meetings of research directors one heard the question: "How do you protect your research work against the clamant demands for additional effort to meet urgent development or engineering problems ?" Various protective devices were tried, including the physical separation of fundamental research from development.

During the war, through sheer force of circumstances, research workers and engineers had to get together on common projects, the research worker feeding new information to the engineer as his design progressed. Curiously enough it worked. Scientist and engineer alike found that they could, without harm to either of them, cross and re-cross the line of demarcation between their two responsibilities.

After the war there was, for a while, a tendency to return to the old philosophy. The return might have been complete had it not been for the appearance on the scene of a considerable number of new development or engineering projects in which the rate of technological development was many times greater than that to which one is accustomed in longer established fields of enterprise. Crystal valves, guided missiles and nuclear power generation are good examples of what I have in mind. In each of these fields, and doubtless in many others with which I am personally less familiar, experience has shown that the old doctrine that the engineer should do the best he can with the knowledge at present at his disposal, by-passing problems which cannot be answered on this basis and throwing them back to the research worker for study at leisure, is no longer valid. On that basis progress is far too slow. The doctrine which has replaced it is that of allocating a period of time for a given project, appointing a team comprising engineers, scientists and specialists of various kinds and telling them to produce the best result of which they are jointly capable within the appointed time. At the beginning of the project an assessment is made of the directions in which new knowledge would contribute to its success and, if there is a reasonable chance of obtaining it in time, objective researches are planned and put in hand. If the engineering requirements change, as well they may as the project proceeds, the research workers are close at hand, completely within the thinking of the engineers, and any modifications to the research program can be quickly made.

That technological advance benefits enormously from this changed way of working there can be no doubt. Obviously care is necessary to ensure that all the research effort is not concentrated on the short term problems. Fundamental research, preferably entrusted to teams protected from the sense of urgency which surrounds a major engineering project, must be carried out. But that is something which for the moment I do not wish to pursue.

Our purpose during this conference is to consider the extent to which the training at present available to our budding physicists prepares them for demands which lie ahead of them. In answering this question one thing to be considered is undoubtedly the effect of this new philosophy on the type of man we in industry seek from the universities. The most important effect of the new outlook is, I think, the emphasis which it places on judgement. The engineer has been accustomed to building on firmly established principles, applying factors of safety which in general he could measure. Now he is frequently more like a general who is continually having to take important decisions on the basis of information which he well knows

to be incomplete. In all the fields that I mentioned as examples this is just what the engineer is having to do to-day. He has no time to await the results of exhaustive life tests or the checking and cross-checking of experimental results or of the multilateral approach to a complex problem. He himself and the scientists who advise him must again and again back their own judgements, calling on their experience to help them to extract all they can from the limited information available to them. The price of success in these highly competitive fields is skill in the interpretation of research results and courage in applying them.

Clearly then one thing we have to ask universities, colleges of technology and all those who train our young people is to realize that we look to them, even more than in the past, to provide us with men and women of sound judgement, well equipped to develop the arts of planning research projects and of extracting as much as possible from them. Information obtained at the university must always be very far from complete and in any case it can easily be extended. Of much greater importance is the understanding of the use of sources of information and the ability to apply it.

Education is like politics. A happy hunting ground for those who are never inhibited from discussing complex problems through lack of knowledge. It must clearly be left to those with intimate understanding and long experience in the sphere of education to determine the pattern of training most likely to produce a desired result. But we must not complain—or perhaps I should say we should not complain, for that we shall in fact do so I have no doubt—that the universities do not meet our needs if we do not tell them clearly what we want. I believe that in this respect there is room for very much closer liaison between the realms of industry and education than exists at present.

Without trying to give answers, however, I would like to pose one or two questions to which I hope this conference may help to provide an answer.

1. Is there sufficient recognition in the courses provided by universities that only a small proportion of the students taking them have the intellectual capacity to become successful fundamental research workers, or do the courses over-extend those who are not of this calibre, and whose future lies in the realm of applied science rather than research, and leave them with a mass of information, much of which they will never use, and a lack of understanding of how to apply that which they do need ?

2. If the answer to the first question does reveal any weakness in our system would there be advantage in reducing the content of information in the course for the Batchelor degree to the level of that required by the man destined for the factory or the development laboratory rather than research, and extending the formal instruction of the potential research worker into the postgraduate period. I am assuming, as it should be safe to do, that the great majority of those destined for research will in fact be encouraged and able to remain in the university for two or three years after graduating in order both to deepen their knowledge in their chosen field and to learn a little of the science and art of research.

3. If there is in our universities too great an emphasis on imparting information and too little on its use, does this stem in part from the fact that the one lends itself so much more easily than the other to measurement by examination ? If so, can this difficulty be overcome ?

4. Finally, and with considerable diffidence, do those in the world of education who are in a position to exert so great an influence on our budding scientists during their most formative years take sufficient account of the wide differences in their intellectual mental capacities, or do they tend to treat all their students as budding Rutherfords, thus creating the impression in their minds that the only really respectable career for them is research and that many of the jobs for which scientists are desperately needed, in the factories as well as the laboratories in industry, are really a little beyond the pale ?

If this feeling, which, whatever its source, undoubtedly exists in the minds of many of the young graduates whom we interview, is in

fact born in the universities, is it really in the interests of the men themselves that this should be so, or would it be better in their own interests and that of the community they serve to encourage them to use such talents as the All Mighty has given them and the university has developed in the spheres in which they can be used to best advantage ?

Our first speaker, Member of the United Kingdom Atomic Energy Authority for Research, Director of Harwell, Nobel Prize-winner, honoured by universities and professional institutions in many countries, and immediate Past-President of The Institute of Physics, needs no introduction from me. I call on Sir John Cockcroft to address us.

Sir John Cockcroft, O.M., K.C.B., C.B.E., F.Inst.P., F.R.S.

(Atomic Energy Research Establishment, Harwell)

The purpose of this conference is to discuss the kind of training for physicists which will best meet the needs of industry and of Government service. I am Director of a research establishment which might be described as semi-Government. We employ about 1,000 scientific and experimental officers and engineers. Twenty per cent of our work is basic science and long-term work in our own fields of interest, and the remainder is applied science or development directed towards specific practical objectives, mainly nuclear power.

As with most research establishments in industry, our work is organized in many small teams, each in charge of a section leader or group leader. A number of separate teams, drawn from different branches of applied and pure science, will work on these specific projects, which are in charge of a senior project leader. We therefore require to recruit physicists who are good experimentalists, and we also need those human qualities which will make them good group leaders in their early thirties and good organizers of projects or larger groups in their later years.

The nature of the problems that graduate physicists will have to face in our field of work cannot be predicted five years ahead. They may be required to work on pure or applied nuclear physics, on the complex orbital problems of high-energy accelerators, on solid state physics, on high-temperature gas discharges, and in many other fields. Our requirements, therefore, do not seem to differ very much in their breadth from those of industry. From a study of the literature, I gather that less than half the scientists employed in industry work on research and development ; the remainder seem to be employed on production, administration, and sales. There seems to be a very welcome tendency also for graduate scientists and engineers to permeate throughout the whole top structure of progressive industry. This is particularly noticeable in the electrical and chemical industries, which were founded on science.

It follows from this that we need to recruit for industry and the Government service physicists who have not only good scientific ability but also the personal qualities which will be more and more needed as they get older. We need, therefore, to have graduates who have had a good general education. They should be able to write reasonably well and to present their results well at meetings and conferences. They should have initiative and drive and they should be able to work to programs. This requirement for the general education of scientists is by no means a new one ; on the contrary, as long ago as the 'seventies Clerk Maxwell deplored the growth of a narrow professional spirit amongst scientists and suggested that " it was their duty to preserve their acquaintance with literary and historical studies," so that perhaps it has always been so.

Like many others, I consider that the schools should be responsible for providing the basic general education of the scientist. The sixth-form student must, of course, read deeply in the subject which he is going to take in the university, but he should devote a considerable part of his time, perhaps one-third, to other fields. He should achieve a reasonable standard of English and a living foreign language, and he should develop

some feeling for history and the arts. I do not believe that it is the business of the universities to remedy the deficiencies of the schools by formal teaching and examination in arts subjects. Many of the universities are, however, providing optional courses of this kind, designed specifically to attract the scientist, and they are proving to be popular. I believe, however, that the best general education at the university stage is through the clubs and societies and the innumerable meetings of the undergraduate world in their spare time. Adequate residential accommodation in universities is of great importance in providing this unofficial general education. We ought, however, to take note of the fact that the increasing content of scientific studies at universities is making it very difficult for science students to take a full part in activities such as athletics. I think that this is greatly to be regretted.

Turning to the university graduate courses in physics, there is a general feeling both in the outside world and inside the universities also that with the increasing scope of modern physics we are attempting to crowd too much into a three-year course. There is, of course, a wide difference between university courses, so that it is difficult to generalize. In Cambridge, which I know best, the first two years of the natural science tripos are devoted to three or four subjects taught at a fairly easy level, followed by a third year in which an attempt is made to crowd the whole of modern physics into two terms of eight weeks' duration. This is really ridiculous and puts an impossible load on all but the cream of the students. It is perhaps not unconnected with this overloading that a very high proportion of the students taking the second part of the tripos now obtain 2·2s or 3rds or ordinary degrees. However, reform is very much in the air at Cambridge and these points are very well appreciated. We may also note that the Oxford honours course in chemistry is already four years in duration. At a recent discussion in The Royal Institute of Chemistry very similar misgivings were expressed by the chemists on both the academic and the industrial sides.

The Chairman has already referred to this point. One solution would seem to be to reduce the content of the three-year course, leaving to a fourth year more specialized and advanced teaching for students who are going on to do research. In that case the three-year course could cover very thoroughly the subjects of classical physics, such as heat and thermodynamics, electricity and magnetism and so on ; and in addition the principal subjects of modern physics, such as nuclear physics, solid state physics and atomic state physics, could be introduced and studied in a general way at the level of a fairly well-known series of textbooks. Rutherford's own Cambridge lectures on nuclear physics are an example of what every graduate and student of physics ought to know.

I feel, too, like many of my colleagues, that the standard of mathematical training should be improved. Students should be trained in particular in how to handle mathematics and apply it to their problems. Too often the lectures are given by professional mathematicians and are too abstract to be of real practical use to the average physicist. The American and Continental universities seem to do better.

Along with this there should, of course, go some experimental training. Two full days a week in the third year is certainly not too much. This experimental training should include the "build it yourself" type of experiment as well as some experience of modern tools and techniques.

The graduate training of theoretical physicists should be rather different, and certainly different from what happens now in many universities. The course ought to be a combination of standard courses in physics and mathematics together with some special subjects such as quantum mechanics. Too often an experimentalist finds himself rather late in life struggling to learn some mathematics to convert himself to a theoretical physicist, and the mathematician finds that he has to learn physics. In Birmingham this hybrid course is being operated with very satisfactory results.

For students going on to do research work in the universities in experimental physics after a three-year general course there would

then need to be more advanced formal instruction in the subjects of modern physics. It would perhaps be desirable for them to be examined in this, and this might be done by making the M.Sc. more important and a preliminary to the Ph.D. This might reduce the number of Ph.D. candidates who show an appalling ignorance of physics at the Viva.

For students going on to do applied research work in industry the universities might organize more postgraduate courses in special subjects such as applied nuclear physics, applied solid state physics and so on. Alternatively, the large research organizations might organize their own internal courses. We might in this respect note the practice of the Bell Telephone Laboratories, who organize courses in their own technologies extending over a period of three years. This certainly seems to have paid in their case.

I now come to the Ph.D. course and the physicist which it produces. At the present time Harwell is taking about half its graduate intake at the Ph.D. level. I have looked up the record of seventeen of our best scientists in the age group 30–40 and find that about half of them came to us with the Ph.D. and half at first degree level. From their records I cannot say that the Ph.D. is a necessity for a successful career in applied research. On the other hand, when research is well supervised there is little doubt, in the opinion of our division heads, that two or three years of university research can be of great value and remarkably reduce the time required to be able to carry out effective work in an establishment such as Harwell.

The pre-war unofficial training of the Cavendish School in experimental nuclear physics, in which one had to turn one's hand to glass-blowing or electronics or high vacuum work or magnet-building, did in fact prove to be of first-rate value for the applied physicist of the war years. On the other hand, we find that in some university research schools the students are working as technicians throughout the whole of their period of study, while in others the techniques and experience acquired are of negative value for later work. In one particular case, the whole practical experience of a Ph.D. student had apparently been limited to passing photographic plates through a domestic mangle to coat them with emulsion. We also find, on interviewing students who have taken a Ph.D., that some of them show an appalling ignorance of elementary physics. A very recent case was that of a physical chemist who had done three or four years' research work and could not even state the second law of thermodynamics or define entropy. This, I suggest, is due to lack of formal training and lecturing in the postgraduate years, and it is in marked contrast to the practice of some of the best United States and Continental universities.

I think that the present practice of Harwell of taking about half our graduates at Ph.D. level, looking out for those who have had good training and supervision, is a good one. The remainder we will take at first degree level and endeavour to provide internally some of the postgraduate training which is really essential in making a good physicist.

I have not dealt specifically with the need for degree courses in "applied physics." Indeed, for our purposes I would not know which subjects of applied physics should be taught in an undergraduate course. In my view, the best way to prepare for work in applied physics is to have a thorough grounding in classical physics combined with good experimental and mathematical training. The specialist applied physics can usually be taught or learned after graduation. Some of it, as I have said, can be taught in postgraduate courses in universities, and the other parts of it should be taught in industry or in other establishments.

There is, of course, the quite separate question of whether we need to combine more engineering training with training in physics, and whether we should try to produce more of the hybrid "engineering physicists." This is done in some parts of North America. There is certainly a need for more engineers with training in experimental physics.

On the whole, I would say that we are well satisfied with the quality of the physicists that we are getting to-day, but I believe that we probably do better than the average run of

industry. I also realize that the needs of industry and the training required for industry may be different from those which we require at Harwell.

R. E. Burnett, Esq., A.M.I.E.E., A.Inst.P.
(General Manager, Marconi Instruments Ltd., St. Albans)

I must make it clear at the outset that I am looking at this problem of the employment of physics graduates in industry from the overall company point of view and not as one having the task of detailed supervision of the work of men in a physics laboratory. During the last ten years I have had an opportunity of interviewing a considerable number of graduates and of placing them in employment and I have watched their progress in industry. I shall refer to universities and university graduates but I hope that many of my remarks will be equally applicable to advanced students in technical colleges. I certainly cannot speak for Government service, in fact I doubt whether much of what I have to say would be applicable to Government research establishments.

May I begin by surveying in a word or two the situation regarding the employment of physics graduates in industry to-day. I feel quite safe in asserting that the majority of physics graduates who take up employment in industry do so in electrical engineering—indeed I believe it is largely the light current or electronic industry into which the majority go to-day. The few statistics I have seen appear to bear out this assumption, but I should be very interested to see an investigation into the facts. If many other industries, such as textiles and heavy engineering, are not getting as many applications for employment from physicists as they would like this is probably because so many are being absorbed into electronics. If there were no vacancies in electronics, however, I doubt whether the other industries could absorb the whole output of the physics departments of universities and technical colleges.

A word about the numbers of men and women graduating in physics annually. Again I have not seen any firm figures on this subject, but I feel sure that there are many more graduating in physics than there are in electrical engineering. In fact I would go so far as to suggest there are almost twice as many physicists as electrical engineers leaving the Universities each year.

(It may be that figures on these two matters are available—if not I suggest that it might be valuable for an appropriate Government department or professional institution to undertake a survey.)

If my impression is correct, that the output of physicists is twice that of electrical engineers and if the majority of physicists who seek employment in industry do so in electronics, we may well ask ourselves where would the electronic industry be to-day without its men with physics degrees.

I should like to cover three aspects of the problem of employing physicists in industry.

1. To consider the departmental organization of an industrial company and in particular those departments in which men with physics degrees are working.
2. To consider the attitude of mind of the young graduate on first entering industry.
3. To say a word or two on postgraduate training in industry.

In electronic engineering organizations there are usually three or four main departments concerned with scientific and technological work.

These are :—

(*a*) The Research Department.

(*b*) The Design and Development Departments.

(*c*) The Production Departments.

It is well known that there are many physicists in the Research Department; it is not so well known, however, that perhaps as many as thirty per cent of the qualified men in design and development are men with degrees in physics.

The numbers in the third area " Production " are few but nevertheless there are some even in these departments.

Taking the research department first.

In a research department it is customary for one section to be known as the physics laboratory in which the work will be devoted to physics in the strictest sense. The rest of the research department will be devoted to investigations with a technological flavour involving the use of techniques peculiar to the industry under consideration. In the electronic engineering industry for example the research work being undertaken will range from fundamental investigations on propagation, the use of new frequencies, new thermionic tubes and so on to the design of new circuitry or work which might more properly be called advanced development engineering. So I can make the point at the outset that only part, even of a research department, is devoted to physics in the strictest sense, the other research departments requiring men with aptitude for applied science. This fact I believe to be true of many industries.

To go yet a stage further to the design and development laboratories. There are, I have every reason to believe, a substantial number of men earning their livings in these activities whose original degree was in physics. Many are team leaders and have working for them engineers, technologists and technicians. It is not always realized by those outside industry that the design and development engineer needs all the basic scientific tools of the research worker and he needs, too, knowledge of the principles of good design, he needs to know something of production so that his designs can be manufactured economically and he also needs to know something of the operational use of the equipment by the eventual customer. The physics graduate naturally knows nothing of these problems when he first enters industry but neither does the engineering graduate. These skills are acquired by experience in industry. It has been said for many years that Britain is usually to the fore in fundamental scientific discovery but in the field of applied science and technology we are said to lag. The physicists have played a major part in fundamental research—they are now playing a great part in technology. I think they can contribute still more in this field.

I will not dwell on the third department which I mentioned earlier—namely, Production, because here the number of men with physics degrees is small but there is no reason why physics graduates should not choose a production department in which to make a career and indeed I believe our efficiency and productivity would benefit if more men trained in basic science and having the inquiring, critical mind of the physicist were to take up appointments in our production departments. In addition there are, of course, special appointments in a production department such as operational research, and linear programing for which the scientific method is essential.

I want to make it quite clear that I believe that the majority of those honours graduates who have the ability, should be encouraged to pursue a career in fundamental science. But should we not point the way to a career in applied science or technology to a large part of the honours school.

When interviewing young physics graduates on their first entry into industry I find so very many of them appear to have only one idea in their mind. That is to take up an appointment in the research department and what is more, they would particularly like to be in one section of research, namely the physics section. Many of those who cannot be given this work of their choice give one the impression that they have been cheated of their birthright and that we are trying to misemploy them as second-rate electrical engineers.

There are no doubt many reasons why the young graduate sees only the possibility of finding satisfaction in working at his own subject of physics. When he is shown an industrial physics laboratory the atmosphere and activities are on the whole familiar and not unlike those he has known during his three or four years at the University. Furthermore, the men who have inspired him at his studies, his Professors, lecturers and particularly postgraduate students with whom he will have come in contact as demonstrators are men whose work is in the pursuit of scientific truth. They are, however, men of outstanding intellectual ability. Only the

best in any one year's output can follow in their footsteps. It is perhaps unfortunate that the majority of the remaining students should believe that there is really no other career and that they should strive to follow a course for which they are not entirely suited.

When one suggests to the young physics graduate that he might begin his industrial career in the design and development departments he shies away. The development departments and the production department are, of course, unfamiliar and I think conjure up in the young graduate's mind the idea only of drawing boards. There is an unfortunate misconception that the work is of a routine and mundane nature not calling for advanced theoretical knowledge and that all the thinking has been done by the research department. I need hardly say how erroneous this idea is and how regrettable it would be if young graduates should get the idea that a career as a technologist in industry is only a second best. It seems unfortunate that so many of these young men should be unaware of and uninspired by the opportunities in applied science. A sound training in the basic principles of the physical sciences and the mental discipline which goes with the study of physics make an excellent basis for careers in this field.

While, as I have said, it is right that those who are able should pursue a career in scientific research, I think it is desirable that the others should, when they leave the university, regard themselves as trained in a basic mental discipline, equipped with basic scientific principles and some mathematics, all of which should form the basis on which to begin a career in industry. If they are willing to learn techniques and acquire engineering knowledge they have the opportunity of entering almost any branch of industry they may choose. If I may use the analogy of the arts man with a liberal education, very few arts men are able to earn their living working on the subject in which they took their degree. Their degree subject gives them a mental discipline to which they subsequently add professional competence acquired as a result of experience in their chosen vocation. Similarly the young graduate in physics should regard himself as having a broad scientific education which has trained his mind and given him a basic knowledge on which he can build. If the young physics graduate is prepared on entering an industrial organization to play his part in any department which can use his abilities rather than confining himself to the department engaged strictly on physics he does three things :—

1. He will be helping British Industry to improve its technology, its design, its overall efficiency.

2. He will be entering a field of work as challenging and satisfying as that of pure research.

3. He will be opening up for himself possibilities of as wide a career and as rapid advancement as is available to him in an industrial physics department.

I wonder, therefore, if it is worth giving some thought to the desirability of facing the fact that only a comparatively small proportion of the men who take a degree in physics can spend their lives working in physics research. Should we think about the remaining larger group. Should those who teach these men let it be known how the majority are likely to earn their living ? Should some thought be given to dividing the physics degree classes at the beginning of the third or final year. Those students who have the ability and inclination might continue as at present to study and learn more advanced and highly theoretical physics. The others might slow down the rate of accumulation of new knowledge and more attention might then be given to teaching them how to *apply* the knowledge they have acquired. A more practical approach might be encouraged. If my original assumption was correct that the majority of the vacancies for physicists in industry are for the electronics industry some thought might be given to the re-introduction of electronic theory perhaps as an optional subject in the final degree examination provided it is treated from basic scientific principles. I hesitate to stress this—partly because my assumption may be incorrect and partly because I may be misunderstood and thought to be over-emphasizing the voca-

tional aspect. Some thought might be given to logic. We do not want men crammed with information which they do not know how or where to apply. We do not want memories—we can build them in the laboratories—we want minds. We want men willing and anxious to apply themselves to the practical problems which must be solved if our industry is to take its rightful place in the world and if this country is to survive.

I know that something on these lines is already being done: Glasgow Royal College of Science and Technology has a sandwich course for a Diploma in Applied Physics, Leeds University had a course in which some of their physics students after two years in the Physics Department spent a third year on electrical engineering—this has, I think, now been dropped. At Cambridge it is not uncommon for a student to take first the Natural Sciences Tripos Part I and then enter the engineering department. Manchester College of Science and Technology has an excellent course and there are others. On the other hand some of our universities appear to ignore the problem or to be making their courses even more theoretical.

I am not, however, advocating that undergraduate courses should cover industrial techniques. The trouble with courses on techniques is that one does not know what will be required in five to ten years time and it is better for the studies to be on a broad basis and techniques acquired later in industry.

Industry on the other hand might encourage the physics graduate to play his part more effectively by postgraduate courses in industry, or in other words by a type of graduate apprenticeship. In the company to which I belong we have for some years taken physics graduates and given those who desired it the opportunity of training somewhat similar to that given to the engineer. This is not uncommon—several large organizations have similar arrangements. Briefly the training period is arranged to give training on :—

(i) Machine Shop practice.

(ii) The organization of production—how things are made—including the reading of drawings and the problems of production.

(iii) A full time course in electronics with emphasis on the principles of electronic design. This course is practical in approach—80 per cent of the time being spent on laboratory work. Towards the end of the course the experiments are in the nature of projects and may take two or three weeks to complete. This period also enables the student to become familiar with test gear, with measuring techniques—what degree of accuracy is appropriate for the particular measurement being taken.

(iv) Functional Training—This is training in the department in which the man is to be employed on completion of his training. This period enables the man to decide if he has made the right choice and it incidentally lets the departmental head wonder if he has also. At the end of this training the young man can slide more smoothly into a team.

(I should make it clear that not all our new entrants take such a course—some prefer to take direct employment and refuse any form of training.)

I have no doubt about the success of training schemes such as this. In my experience, group and section chiefs are always anxious to get hold of men who have done such a training course even though they may already have as many untrained graduates in their sections as they can absorb.

The introduction of young graduates into industry presents a two-fold problem. I have considered the attitude of mind of the young graduate and it is only fair to say that we also have to change the attitude of some of the senior people in industry to-day. They must realize that many more young men are being given the opportunity of having a university education. They will not get such good quality material coming up the " hard way " —but in the future they will have to fill many more posts in all departments in the organization with graduates because of the increasing complexity of the problems. The management must take the trouble to find out what the young graduate can reasonably be expected to know, and what he cannot be expected to know. They must guide his early training, help him to acquire the

knowledge he needs and create an atmosphere in which he can develop.

If I may summarize what I have tried to say, I would begin with the assertion that we are receiving good physicists from the universities and technical colleges. We are also receiving good engineers. We are *not*, however, receiving men who fall between these groups—engineering/scientists or scientist/engineers—call them what you will. Of the need for such people in considerable numbers I am convinced. I think it would be worth somebody's time investigating whether the opportunities for men to pursue physics *qua* physics are more limited than is popularly supposed while the greater need is for applied scientists or scientist/engineers. It may well be said that it is not the function of the universities to produce men trained in the applications of science. If this is so I would venture to suggest that it is desirable for a fair proportion of the men and women leaving universities to be aware of the opportunities in technological work and the great need of industry for them. If this were done I believe that the young graduate would enter industry with a more positive and optimistic attitude towards his initiation and training and have a better idea how he might steer his career towards a senior position as he acquires experience.

This country faces a struggle for survival, particularly in the face of competition from the U.S.A. and the U.S.S.R. When we look at the frightening figures of men receiving graduate training in U.S.S.R. and the U.S.A. I suggest we must conclude that these two countries cannot be training men and women in these numbers for pure science. The majority must clearly be intended for applied science and technology. We must take note of the trend, and bias more of our young professional people in a similar way towards the application of knowledge.

We are constantly being told that industry must produce more goods, with better design and at competitive prices if we are to retain our place in world markets. Our ability to do this rests very largely on our scientists and engineers. It rests in the first place on our fundamental research, but eventually on our technology. I want the physicists to bring their knowledge and intelligence to bear in this struggle and to realize that they have a great part to play. I do not want them to feel that their contribution must be confined to the back room—to fundamental research. I think it should be *known* that so many men with physics degrees are engaged in the applications of scientific principles. For those willing to take the course I have tried to indicate, the challenge is stimulating, the career is rewarding and there is the real satisfaction of knowing that one is playing a vital part in raising the standard of living of one's country.

Dr. J. Thomson, M.I.E.E., F.Inst.P.

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In discussing " the kind of training for physicists that will best meet the needs of industry and Government service " we are liable to find as many opinions as we have delegates, for there is no more controversial subject than education. I must, therefore, crave your indulgence for advancing for your consideration certain views which may well be regarded as unorthodox and which certainly call for a considerable modification of present courses in universities and technical colleges. Let me say immediately, however, that the modifications proposed are spiritual rather than organizational and to that extent at least should be simpler to apply !

One of the principal difficulties we have all encountered in discussing the subject of the conference is the definition of " applied physics." As Professor J. A. Crowther said many years ago: " Physics is one and indivisible." " Applied physics " stresses the object of the work rather than the work itself. It is very doubtful if there is any difference in outlook between " pure " and " applied " physics. In any event we are all agreed that industry and Government require

the best educated scientists of the highest intellectual calibre. Since we all depend for our daily bread on the productive capacity of British industry, it is self-evident that we have a moral duty to serve industry with the cream of our scientific ability. Moreover, we have a double duty in this respect. The problems of the industrial world have grown in proportion to industry itself, but the men who have to solve these problems, good though they are, are not intellectually in proportion. The best men we can find will still be faced with problems which will strain their abilities to the limit. Unless one has been concerned with industrial problems intimately it is hard to realize their complexity and profundity. Academic scientists seldom make mistakes, but when they do it is of little importance. Time rectifies the error and only the reputation of the erring scientist suffers. But a mistake made by the industrial scientist may cost the nation millions of pounds without it ever being realized that a mistake has been made. Integrity as well as intellectual ability is an essential quality in the industrial scientist. The academic scientist is able to choose his subject and to set the limits of the investigation. He is therefore a specialist in the true sense of the word. The industrial scientist has to take the problem as he finds it with *all* its implications. He can, and often does, break it down, but to do so he requires a much more generous understanding of basic science. He is *not* a specialist although he may employ them. In respect of difficulty there is no comparison between the two types of effort.

The President of the Bell Telephone Laboratories, Mr. M. J. Kelly, calls the activity which I imagine we wish to foster " creative technology," by which he means applied research. So far as this is the job of the physicist, Mr. Kelly's conclusions are interesting. He states in an article in *Electrical Engineering* that " the larger the basic science content of the curriculum the better the course " ; that " for the development, design and engineering areas of ' creative technology ' industry can well provide the training " after a man has had a four-year graduate course in a College, but that " for the research and fundamental development areas training to the doctorate level in science or engineering is necessary " and that " training in this level is best done in an academic institution."

The President of the Massachusetts Institute of Technology, Mr. J. K. Killian, in an address to the American Association for the Advancement of Science, said " it is a better policy to have an increased pool of exceptional talent," " employers are looking for a sound education in fundamentals, for analytical power, for a grasp of new and advanced fields of technology, that is, they are looking less for specialized competence than for the versatility necessary to enable a man to follow any one of a number of specialties. In the basic sciences the most pressing need is for the scientists with imagination and trained creative power who make the discoveries and generate the new ideas which advance science." He also advocated a larger content of basic science, less compartmentalism and more emphasis on materials, thermodynamics, fluid flow and energy conversion, thus breeding a new type of engineer more adaptable to the changing technology. Finally, he stated that it is the responsibility of the colleges to stress the unity of all knowledge and to put an end to the mutual derogation of scientists and humanists.

With these views expressed by two of America's most responsible authorities I heartily concur, and I should like to put forward for your consideration four propositions, independently conceived, but in agreement with the views just stated, namely:

(*a*) that degree and diploma courses in applied as in pure physics should be re-cast to emphasize the unity of our thinking about natural phenomena, eliminating as far as is possible the artificial and outmoded classification of parts of the subject into heat, light, sound, electricity, magnetism, atomics, nucleonics and electronics ;

(*b*) that the significance of mathematics as an arithmetical tool should be emphasized, but that its use as a research tool should be discouraged until the student is in a position to realize its limitations ;

(*c*) that teachers should set themselves

the task of explaining or describing every phenomenon without recourse to symbolism ; and

(*d*) that science students should be taught, both from history and by experiment, that a scientist must make his own observations and cannot leave this work to a junior, or, least of all, to a technician.

With regard to the first of these propositions I feel sure, both from my own teaching and research experience and from the experience of many of my colleagues in Government and industrial research, that the chief criticism of our present teaching system is its compartmenting of what is, in fact, a single unit—physics. After all, *physics comprises the investigation of the relationships between natural phenomena*. Although it may be useful from a book-keeping point of view to divide up the subject, it obviously detracts from the student's appreciation of the unity of thought to have to switch from one compartment to another. It was the growth of understanding, fed by the philosophy of the self-consistency of scientific theories, which bore such wonderful fruit in earlier days, and as our comprehension of nature deepens and widens it becomes all the more important to refuse to admit artificial barriers. This, incidentally, is one of the reasons for Mr. Killian's advocacy of the study of thermodynamics, since this is *one* method of unifying teaching. The thermodynamic method can be applied to any class of phenomenon. I do not agree that it is the best method, for I have a personal predilection, shared by most of our fellow-countrymen, for a pictorial presentation, but it is the mathematician's way out of the real difficulty.

If our University and Technical College teachers would set themselves the task of describing all physical phenomena in terms of elementary atomic and molecular concepts, and particularly if they were not afraid to trespass on the ground conventionally trodden by the chemist, a much simpler and more useful picture of the Universe could be conveyed to the student, a picture which would excite curiosity and stir the imagination. Teachers need not be afraid of the gaps in their pictures. Gaps exist ; explanations are not always possible. But the student who is trained in this way is brought quickly to a realization of where the gaps are instead of having a vague idea that science advances on a broad front, clearing all obstacles from its path as it goes. The frontiers of knowledge are not approached by a long and arduous journey through well-mapped terrain. They face you round every corner.

The proposal that we should eliminate the out-of-date partitioning of physics should not be interpreted as a criticism of teachers, either in colleges or schools. After all, science has advanced at a fantastic pace in the last half century and it would have been intolerable for the educational system to have moved in phase with research and development. The majority of school teachers have already taken steps to unify physics, as can be seen from an examination of the school text-books written since the last war. For example, wave-motion, or, more exactly, wave-mechanics in the broad sense (not the de Broglie sense) is now taught as an introduction to optical, mechanical and electrical phenomena, while the structure and properties of crystals are studied on their own merits with illustrations taken from all of the classical sub-divisions of the subject. At University level, where students are not so much taught as given the opportunity of learning, good integrating text-books are uncommon. Improvement is desirable, if embryo scientists are to be given the broad outlook on the universe which will give them confidence in facing industrial problems. A problem never falls neatly into a category of the schools : it is merely a problem.

My second proposition is that mathematics should be presented first as a tool, allowing a quantitative result to be obtained quickly and accurately, and that only in the later stages of training should its other function be disclosed. Its second function is that its symbolism offers a short-hand generalization of value in suggesting a fresh attack on a problem. Most important of all it should be made very clear to the student that mathematical work is non-creative.

This is of great importance in view of the distorted outlook possessed by many of our

younger graduates. Almost all directors of scientific establishments confirm that the physics graduate of to-day regards mathematics as we must imagine the ancient alchemists regarded the philosopher's stone. Mathematicians themselves, of whom I am one, are quick to admit that creative thought can only at best be suggested by transformations, but the obeisance of the physicist, chemist and engineer to this tool of his trade is something which requires correction. I can confirm from personal experience that it is not uncommon for a physicist who has been asked to uncover new information to imagine that he can do so by futile gymnastics in symbolism.

The secondary reason for pressing this point of view is that even the brilliant student is occasionally caught napping by mathematics and is led to imagine that he understands a relationship because he can write down an equation to describe one aspect of it. Reminding ourselves that we are searching for methods of increasing our potential of exceptional talent, we must be very careful not to mislead the inexperienced by a too facile use of symbols. As one brought up in a severely mathematical atmosphere, I speak with feeling.

This brings me to my third proposition which is the other side of the same coin. If a teacher uses mathematics to do more than give arithmetical value to his description of relationships, he is failing in his duty to his students. It is so easy to describe phenomena symbolically, and so satisfying to generalize on the basis of the symbols, that it is not surprising that we all fall into the trap from time to time. A good exercise is to explain Fraunhofer diffraction without the use of mathematics, or, at least, only using the most elementary arithmetic. A better exercise is to explain the variation of Newtonian *mass* with *velocity* without introducing a four-dimensional system. I firmly believe that if a teacher has to have recourse to mathematics for any other purpose than a computational one, he does not properly understand what he is trying to describe. In certain cases he has to admit this to the student after which symbolism is in order.

My fourth proposition—that students must be taught never to delegate to others observations on a phenomenon or process—is derived from a careful study over the past ten years of the gradual degradation of the working scientist in Government and industrial laboratories. By 1946 there was a well-marked tendency for the more senior scientists in Government laboratories to shut themselves off in offices where they were supposed to do their thinking, and to leave to their juniors the construction of laboratory equipment and the observations to be made with the aid of the equipment. Everyone is agreed that scientists should not waste valuable time trying to do what well-trained technicians can do better and, so far as making apparatus and equipment is concerned, the tendency referred to was a good one. But when it comes to taking observations—to doing the experiment—it is fatal to leave this to a junior or to a technician, no matter how well equipped the latter may be, to measure and record. The anomalies in the experimental results are usually much more important than the predicted values : the unexpected behaviour of the apparatus is of vital importance ; and both anomalous results and unexpected behaviour can be neglected if the observations are made by someone who has not been intimately concerned in the design. It is true that first-class team work can give assistants a better appreciation of the situation, but it cannot replace the live interest of the man responsible for the experiment who may himself only be dimly aware of its potentialities. Even in my limited experience I have noted on many occasions how effects of vital importance have been neglected or missed entirely by the junior scientist left to take observations unaided by his leader who designed the experiment.

Unfortunately the tendency to leave *all* the work on the bench to junior scientists and technicians is fostered by the accountants, who, accustomed to factories and offices, feel that it is wrong to pay a man who is apparently working with his hands and not with his head a salary equal to that earned by the manager of the factory or the office executive. It cannot be too strongly stressed that the

experiment is the heart of scientific endeavour and that the experimenter must cause things to happen with his hands in order to acquire the information on which the brain can operate. Should we have had the scientific age if it had not been for the experimental skill of Faraday, Thomson, Wilson, and their like ? These men may have done more than they should in making their apparatus, but they could not have made their discoveries by leaving observations and records to others.

A great responsibility rests with science teachers in this matter. Without in any way detracting from the importance of scientific administration, they have to ensure that students properly appreciate the distinction between (*a*) the scientist who invents, discovers and investigates and who must work for the greater part of his time in the laboratory, and (*b*) the scientist who directs and administers, who has to make judgements and to ensure that objective consideration is given to the policy of a group. Both jobs are important and, speaking generally, are probably equally important. One of the great tragedies of our time, which is reflected in the need for the present Conference, is that so many of our scientists, capable of invention and discovery, are forced by circumstances to spend a large part of their creative life in the direction and administration of groups. This is most tragic, perhaps, in the universities, where the professional staff finds itself ringed round by administrative problems to the detriment of creative effort. Nothing can take the place of the first-class creative brain working in co-ordination with hand and eye at the bench.

Turning now from the general to the particular, may I propose for your consideration the following specific courses, based on the propositions already discussed which, I should remind you, are in general agreement with the views of the President of the M.I.T. and the President of the B.T.L. :

(*a*) A basic physics course, not divided into compartments, but stemming from a thorough discussion of the atomic and molecular structure of matter, and comprising illustrations of the application of fundamental physical laws to the description of major phenomena. This course should have as its object describing the universe in terms of the simple physical principles, so as to leave the student with the confidence that, faced with a new effect (i.e. new to him) or a new event, he will be able to explain or describe the effect or event within the framework of these principles. Full use should be made of the generalizations already within our grasp as a result of the work of the classical mathematical physicists, but so far as it is possible, these generalizations should be translated into pictorial form and their physical aspects should be emphasized. Where gaps in the teacher's knowledge occur, these should be noted as gaps, giving the student the opportunity to fill them by reference to other sources or to recognize them as gaps. The temptation to discuss detail should be avoided, and in particular a clear distinction should always be made between the major and minor, or between first order and second order effects.

The course should aim at exact calculation only where this is likely to help the student to understand, but in every case the order of magnitude of the quantities involved should be discussed. This is implicit in the concept of pictorial teaching ;

(*b*) a basic mathematics course, the object of which is to show the student how apparently impossible tasks can be performed by the use of mathematical techniques. Indeed, this course should be entitled Applied Mathematics, since every new technique should be illustrated by its application to a physical problem. The course should be complementary to the basic physics course in the sense that its choice of subjects should be determined by the effects studied in physics. To take a trivial example—since many of the physical phenomena studied will involve recurrent phenomena, the techniques of Fourier analysis and Laplace transforms should be linked to the physical investigations. Once more the student should not be invited to perform exact calculation of a minor nature. His attention should be directed to the fact that all mathematical processes, since they are purely deductive within a framework of postulates, can be

exactly simulated by a mechanical or electronic computer, and he should by actual demonstration be re-assured that even the most complex calculation can be performed mechanically. This would lead him naturally to the important conclusion that the formulation of the problem in the appropriate mathematical form comprises the creative part of his work as a physicist ;

(*c*) A basic science course concerned with the discussion of scientific advances outside the conventional realm of physics. This course would have as its object the education of the student in different disciplines and the cultures of other sciences. A subsidiary aim would be to introduce the student to the techniques available in other fields. Without this general background the student is liable to lose confidence when confronted after graduation with a world in which chemistry, biology and geology play a most important part. The method of teaching should be similar to that employed in the basic physics course. It should be pictorial and descriptive, so that the student is able to link up astronomical and biological problems with those in his own domain of physics and to realize that the common factor of self-consistency runs through his universe.

(*d*) Finally, no course in science is complete without a reasonable discipline in business methods and administration. This should have as its object to bring the student to realize that his work as a scientist is done within the framework of a sophisticated society in which he has obligations to all around him. The importance of personal and scientific integrity should be implied. The force of the democratic method and its relationship to the concept of leadership should be taught by reference to historical and contemporary problems, to give the student confidence on leaving college that he understands the principles governing good relationships between staff and staff, and staff and management.

I advocate four courses :

(*a*) Principal science — physics ;

(*b*) Principal tool — mathematics ;

(*c*) Other sciences — chemistry, biology, geology, astronomy ;

(*d*) Personal relationships — business methods and administration.

The courses should be aimed at the exceptional student rather than at the average student, but if they are formed in the manner suggested they ought to be suitable for both. We do not know at this moment how many first class creative technologists the country can produce, for we do not possess an educational system which would bring them to light.

DISCUSSION

Mr. O. W. Humphreys : There are two points in Dr. Thomson's address on which I should like to comment. He said many things with which I agree completely, but two in particular impressed me.

The first was that the scientist should make his own observations. The importance of a scientific experiment, as Dr. Thomson so rightly says, is so often the unexpected. You cannot teach the technician to notice the unexpected, or, if he does notice it, he probably thinks that it is because he has made some mistake, and he is ashamed to mention it.

The other point was that too many able scientists have to spend too much of their time on the administration and organization of groups. In some organizations that is the truth and in all organizations it is a danger. The pattern to which I have tried to work, in order to avoid this, is that we must have groups and we must have administration and organization, because we do not want anarchy in a research laboratory, but there are certain people who have qualities and abilities which suit them to do that sort of work, and they are by no means always the outstanding scientists. Let those people be the group leaders. If the group is a large one, there can be associated with the group leader an outstanding scientist without administrative responsibility, but responsible for the scientific well-being of the work of the group as a whole.

This is a pattern which we have been employing increasingly, and I think with considerable benefit. What has to be made absolutely clear, in order to get people to accept that philosophy, is that group leadership does not necessarily imply seniority. The group leader has a defined administrative responsibility. The scientists agree that there are certain things which they will leave to him and on which they will follow his lead, but the fact that they do so does not in itself indicate that he is in any way superior to them.

Dr. J. V. Dunworth (*Atomic Energy Research Establishment, Harwell*) : Sir John Cockcroft regrets very much that he has had to leave and has asked me to deal with questions on his paper. Although it is not strictly a matter of education, I feel sure he would like me to comment on the point on which the Chairman has just spoken. At Harwell we did realize the danger of having the most able people in positions of responsibility where they are loaded down with administration and out of contact with scientific work in the Laboratory. There are two quite specific methods by which it has been ameliorated.

The first is that of having an administrative officer in each division, which is perhaps somewhat novel in a Government department. As a result the Division Head is freed from all minor administration and can keep in daily contact with work in laboratories and in the various groups.

The second method is the individual or personal merit post. This is something which we introduced at Harwell some years ago as a means by which outstanding scientists could have a senior rank within the Civil Service hierarchy without any measure of responsibility. Furthermore, senior staff can change from a post with responsibility to one without and vice versa. In my own division I have at the moment two people with the rank of Deputy Chief Scientific Officer who are without formal responsibility. The salary scale for such a position is around £2,500. Also in my division I have another person who started in the ordinary responsibility grade, transferred for three or four years to a personal merit post, and recently has transferred back to a responsibility post. Whilst in the personal merit post he was without any staff under his control.

Mr. E. B. Pearson (*Royal Military College of Science, Shrivenham*) : Mr. Burnett referred to the large number of physicists who, when they go into industry, find themselves doing work which tends to be concentrated in the light electrical field. Would it not be a good idea to have some generally accepted scheme whereby graduate students, final year students, and also their lecturers, would be allowed to visit industry and see for themselves the sort of work which has to be done there. I do not know whether that is done regularly under present conditions but if not I imagine it would be rare to find a student writing to a firm and saying: "I want to come and see what you are doing." I wonder how many physics lecturers, particularly those who have been acting as lecturers for a long time, have much opportunity to go into industry and see what physicists are doing nowadays in that field. I am thinking particularly of electronics, computing, servo-mechanisms and so on, which cannot be accommodated in the normal physics curriculum taken by undergraduates.

The other alternative which might be useful would be to set up an organization so that industry could provide visiting lecturers. We do that at Shrivenham for our ordinary graduate and postgraduate Army and other Service students who have, from time to time, lectures by visiting experts who speak on the applied aspects of certain basic subjects. If the university student could have such lectures it would be a good thing and would give him an idea of where his university training was leading him, otherwise he may get ideas that some of it is not going to be much use to him after leaving the university.

I have been invited to give a lecture next year at Nottingham University, to the final honours electrical engineering students, on some applications of servo-mechanisms. The lecture will be one of a series to be given by different lecturers. Similar schemes could

be arranged for physicists. I should be interested to know whether or not there is a general feeling that :

(*a*) organized visits to industry, possibly in vacations, and

(*b*) lectures by applied physicists from industry and elsewhere ;

should be sponsored on a much wider scale than at present for physics students.

Mr. E. K. Ferguson (*British Petroleum Co. Ltd., London*) : We have in my company a very highly organized scheme of vacation training, whereby physicists and other scientists and technologists get an intimate look at the industry as it actually operates. These courses are run in co-operation with university teachers, so that there is a close connexion between the work which is being done and the theoretical studies of the students concerned. Secondly, people who have not done vacation training with us are introduced to the company and allowed to look round our refineries and research stations when they are thinking of applying for a job with the company.

We are closely in touch with university teachers, and university teachers also visit the company and see our refineries and discuss the work which is being done with our people who are working in the refineries. They also visit our research stations and meet there the people who are working on problems of particular interest to them and discuss the problems in quite considerable technical detail.

Mr. E. M. Wareham (*W. H. Sanders (Electronics) Ltd., Stevenage*) : I have never before heard views with which I so profoundly agreed as those expressed by Dr. Thomson to-day. Following on from a point which he raised, I would like to contribute a suggestion based upon the relative roles of the scientist and the engineer.

Considering the scientist in the formal light of an investigator, his function would seem to be concerned with the acquisition of knowledge both factual and procedural.

The engineer is primarily concerned with the manufacture of equipment of some sort. He is therefore a constructor and he applies a formalized procedure to the solution of the problems which arise in this context.

Broadly speaking I think that it may be possible to divide people into two categories according to their mental processes. These I might call visualizers and non-visualizers. There is, of course, no sharply defined boundary but I believe that some people have pronounced tendencies to think in terms of visual imagery. Other people have no reaction at all to any form of pictorial representation of intangible phenomena. This class of thinker does not seem likely to me to find much satisfaction in engineering but may well succeed as theoretical scientists.

If these views are accepted it seems that there is a case for considering the possible value of a study of teaching methods with the object of a separation of the techniques to be used for research scientists and for engineers.

Dr. N. F. Astbury (*Royal Aircraft Establishment, Farnborough*) : I have had a little experience in all the fields represented here to-day. I have been, and am once again, in a Government establishment ; I have been a university teacher, and I have been involved in industrial research. On and off, therefore, over some years I have thought about the problems which have been put before us this morning, and I find myself in close agreement with much of what has been said.

The first point which I should like to make, and which I put as a proposition, is that it is impossible to train at a university first degree level a person who will be immediately useful in any industrial or Government laboratory. I think that we must accept that as fundamental. An impression has been created, I think, and it has been evident in much of what has been said this morning, that there is a minor discontinuity in a man's career at the end of his university education. I think it is the duty of industry, and indeed of the State as represented by the Government laboratories, to remove that discontinuity and to continue and taper off the training of the man in his new job.

It is no new phenomenon to recognize that the new graduate is not of immediate value.

The medical profession recognized it several years ago. In the teaching profession the same thing is found. We are not, therefore, confronted with a new problem ; we must admit its existence and admit that it is the responsibility of the employer to continue the training of the young graduate ; because I do not think that, with the best will in the world, any university, whether an ordinary university or a university of technology, can produce a graduate who will earn his keep in the first few years of his professional career. Nor do I think that the Ph.D. candidate is in much better case. He has often worked in a very narrow field, and, unless he is fortunate enough to continue working in that same field, he will be at much the same disadvantage as the man with an honours degree.

My second point is the one made by Dr. Thomson on the unification of the teaching of physics. It is a matter on which I agree whole-heartedly with him and on which I have tried to make my own small contribution. From the point of view of the teacher, the departmentalization of physics is disastrous when the field is now so wide. I am no longer a teacher, but I think that all teachers must try to follow Dr. Thomson's sound advice there. To follow that advice successfully, however, depends on being able to deal with a rather difficult factor, what I would call the negative feedback factor in instruction. What has happened is that too often textbooks have been referred to earlier syllabuses and later syllabuses have been referred to earlier textbooks, thus producing a high degree of negative feedback, amounting almost to *statis*. It is up to all teachers and those who write textbooks to try to unify the teaching of physics.

The only point on which I venture to join issue with Dr. Thomson concerns his rather severe strictures on the use of mathematics. I have always found mathematics at worst a useful broom to clear the floor before commencing operations. As for the use of mathematics in teaching, I can well take Dr. Thomson's point that north of the border one can lose more friends by talking about this than by talking about theology. I would draw attention to the work of Ampere, one of the greatest geniuses of all time, without whose work Maxwell's magnificent edifice might have been delayed ; and I would ask Dr. Thomson how what Ampere did in his experiments and in the interpretation of them could be done without the use of formal mathematics.

My final point is the place of the humanities in the teaching of science. I particularly liked Sir John Cockcroft's point, that it is the responsibility of the schools to give the necessary breadth of education to the students. In one of my oversea appointments, which was at a university of technology, we had a course in the humanities ; we had a faculty of humanities and a professor of humanities, and the proposition as I saw it was that large doses of culture should be forcibly injected into the unfortunate student at such opportunities as presented themselves in an already overcrowded course. That is quite wrong. I believe most earnestly, with Sir John Cockcroft, that it is the function of the schools, and that the additional culture or information which is desirable can be encouraged by the normal processes of social communication at the university. I plead most strongly against the idea of forcibly injecting culture into science or technology students.

Professor A. J. C. Wilson (*University College of South Wales and Monmouthshire, Cardiff*) : There are three points which I should like to make. Two of them have been suggested by Dr. Thomson's address, and the third has been touched on only very briefly by any speaker. Of the two suggested by Dr. Thomson's talk, the first is that I was a little unhappy about his reference to mathematics. That has partly been compensated by two subsequent speakers, one of whom very helpfully divided scientists into those who visualize and those who think symbolically. I should like to tell a story about that. At one time in Cambridge three of us were working on some X-ray diffraction effects produced by cobalt. This work was written up in the form of two papers for The Royal Society, the first a long and careful

description of the experimental work and a simple theoretical explanation, and the second a rather more complicated theoretical explanation. These papers, before publication, were given to a very eminent professor for his comments, and were returned with a few pencil notes in the margin. One of these, which occurred half-way through the second, more mathematical, paper was: "At this point I first realized what the work was about." Obviously he was an extreme case of a non-visualizer, but that did not make him any the less a useful scientist.

Secondly, Dr. Thomson talked about the overloading of scientists in industrial laboratories and elsewhere with administrative work. It is two years since I became a professor of physics, and it seems to me that that is perhaps even worse in universities than in industry, because since that time I have had very little contact with the research of the department. (I am a little unfortunate in that circumstances in Cardiff give me a double dose of committees.) I sometimes envy some of my American colleagues in universities where the structure of the department is different and there are several professors who take it in turns to act as head of the department, for possibly two years at a time.

Turning to something entirely different, school teaching, I feel, and it has been obvious from some other remarks this morning, that too much is being attempted in the way of teaching physics in schools, to the detriment of the general education of the boys or girls. If you look at the syllabus for the advanced level G.C.E. in physics, you will see that it would do just as well as the syllabus for an honours course. It is obvious that it cannot be taught properly at school, and the attempt to get in a good bit of modern physics means that the fundamentals are scamped. We find boys coming to college who not only cannot apply Newton's laws of motion but cannot even state them. I think that in order to get a better output of physicists both for applied work and for research we have to devote much more attention to teaching fundamental physics in the schools, and much less to teaching the frills of physics. That might also leave some time for the students to learn to write grammatical English.

Dr. A. von Engel (*University of Oxford*): I come from Oxford, the place where people talk now about traffic problems, and also a place where other things change quite rapidly. I should like to remind you that the legislators in Oxford have been very wise men, men of great foresight who in 1938 included as the first in the list of special subjects "applied physics."

What does this mean? It means simply that if you take a three-year course in the Honours School of Natural Science and obtain a B.A., you can apply to stay for one year to read a special subject or for three years' study to take a D.Phil., and you can choose applied physics. I have inquired how many people have taken this course. The answer so far is nil, but that does not matter. We have made this provision in our statutes, which I have brought with me to show to anyone who may be interested.

One of the lecturers mentioned that physics is subdivided into heat and light and so on and that no connexion exists between these subjects. This does not apply to Oxford. Although in the final examination we have five papers which are called light, electricity and magnetism, etc., you will find, if you look into the papers, that the questions connect the different subjects. For example, in a paper on properties of matter you will find essay questions or questions with a numerical example which require a knowledge of, say, applied electricity, optics, or atomic physics.

I can speak for Oxford alone and not for my sister university, when I say that there is a close link between the different subjects in examinations and in teaching. It is self-evident, since we have a tutorial system, that one cannot expect that an undergraduate when taught optics will not be allowed to ask questions on the mechanism of this and the model of that. There need be no fear that we are teaching in different compartments.

I want to make a final point which has nothing to do with degree courses, and I

hope that you will forgive me if I mention it. It has been said by a previous speaker that undergraduates get a wrong idea about industry. As far as my pupils are concerned that may be so, and many of them do not like to accept posts in industry, but this is not because we influence them wrongly. We tell them the truth so far as we see it, and sometimes we paint a rosy picture and even, perhaps, too rosy a picture. Where do they get that information ? They do not get it from their tutors ; they get it from their friends who are already working in industry. If those people give a wrong picture, it seems necessary to do something to make them feel happier, so that their reports do not influence the younger generation.

Mr. O. W. Humphreys : I am afraid that the time has come to close the discussion, but it will be continued this afternoon after Professor Blackett's address.

I promised to see whether we could get any information on the numbers of physicists and engineers. The only information which we have been able to find in the short time available is the numbers taking honours degrees in these two subjects in 1954-55. The result is to me most surprising. The figure for physicists, adding men and women together, is 531, and the figure for electrical engineers is 158. Since we all know roughly the relative proportions between the number of professional engineers and the number of professional physicists there is obviously something to be explained here. The explanation may be the high proportion of electrical engineers who enter their profession other than through the path provided by a university degree. There is also the point that these figures are not quite complete, because they refer only to honours degrees, but I have no reason to think that that alters the picture very much. It looks as though Mr. Burnett is completely vindicated.

Reports of the other sessions of this conference will be published in later issues of the " Bulletin." The complete proceedings will also be published in booklet form and will be available for sale.

Forthcoming Institute Meetings

Feb. 15 Education and Industrial Spectroscopy Groups — At the Institute's House, 3 p.m.
" The Education and Training of Spectroscopists " — Tea 4 p.m.
Principal Speakers :
Dr. H. Powell (British Petroleum Research Station, Sunbury-on-Thames)
Dr. G. H. Beavan (National Institute for Medical Research)
Mr. W. R. S. Garton (Imperial College of Science and Technology, London)
Mr. A. S. Nickelson (U.K.A.E.A. Research Group, Woolwich)

Feb. 15 Non-Destructive Testing Group — At the Institute's House, 6.30 p.m.
Joint Meeting with the Acoustic Group of The Physical Society
" Acoustics in Non-Destructive Testing "
Dr. R. W. B. Stephens, F.Inst.P.
(Imperial College of Science and Technology, London)

Feb. 19 Electronics Group — At the Institute's House, 5.30 p.m.
" Modern Magnetic Devices in Digital Computers " — Tea 5 p.m.
Dr. G. R. Hoffman
(University of Manchester)

Feb. 20 London and Home Counties Branch — At the Institute's House, 6.30 p.m.
Branch Annual General Meeting — Tea 6 p.m.
followed by
"*Non-Numerical Applications of Digital Computers*"
DR. A. D. BOOTH, F.Inst.P.
(Birkbeck College, London)

Feb. 25 Scottish Branch
In the Natural Philosophy Department, University of Edinburgh, 7.15 p.m.
"*Instrument Transducers*"
DR. J. THOMSON, F.Inst.P.
(The British Scientific Instrument Research Association)

Feb. 26 Scottish Branch
In the Natural Philosophy Department, University of Glasgow, 7.15 p.m.
"*Instrument Transducers*"
DR. J. THOMSON, F.Inst.P.
(The British Scientific Instrument Research Association)

Mch. 5 North Eastern Branch — At the Science Laboratories, Durham, 5.30 p.m.
"*Solid State Image Amplifiers*" — Tea 5 p.m.
PROFESSOR G. F. J. GARLICK, F.Inst.P.
(University of Hull)

Mch. 6 Scottish Branch
In the Natural Philosophy Department, Marischal College, Aberdeen, 7.15 p.m.
"*Research in Nuclear Physics at the University of Glasgow*"
PROFESSOR P. I. DEE, C.B.E., F.Inst.P., F.R.S.
(University of Glasgow)

Mch. 6 Education Group — At the Institute's House, 6 p.m.
"*An Experiment in University Education*" — Tea 5.30 p.m.
PROFESSOR F. A. VICK, F.Inst.P.
(University College of North Staffordshire)
This meeting will be preceded at 4.30 p.m. by the
Group Annual General Meeting

Mch. 7 Midland Branch
Visit to the Coal Research Establishment, Stoke Orchard, followed by a lecture on some of the physical aspects of coal research.
Number limited to 25.

Mch. 8 Liverpool and North Wales Branch
In the Department of Electrical Engineering, University of Liverpool, 7 p.m.
"*Pion Physics*" — Tea 6.30 p.m.
PROFESSOR J. M. CASSELS
(University of Liverpool)

Mch. 8 Manchester and District Branch
In the Bragg Building, University of Manchester, 6.45 p.m.
"*Some Aspects of Vision*"
DR. R. A. WEALE, A.Inst.P.
(Institute of Ophthalmology)

Mch. 8 South Wales Branch — At the University College of Swansea, 5.15 p.m.
" *The Recording of Faint Optical Images* " — Tea 4.30 p.m.
PROFESSOR J. D. MCGEE, F.Inst.P.
(Imperial College of Science and Technology, London)

Mch. 11 Scottish Branch
In the Natural Philosophy Department, University of Edinburgh, 7.15 p.m.
" *The Velocity of Light—a survey of the measurement technique* "
DR. L. ESSEN
(National Physical Laboratory, Teddington)

Mch. 12 Scottish Branch
In the Natural Philosophy Department, University of Glasgow, 7.15 p.m.
" *The Velocity of Light—a survey of the measurement technique* "
DR. L. ESSEN
(National Physical Laboratory, Teddington)

Mch. 13 Yorkshire Branch — At The University of Sheffield, 5 p.m.
Branch Annual General Meeting
followed by
" *The Properties of Materials in Nuclear Reactors* "
DR. P. MURRAY
(United Kingdom Atomic Energy Authority)

Physical Society Meetings

Members of the Institue are invited to attend the following meetings of The Physical Society :

Feb. 14 — Low Temperature Group
" *The Magnetic Properties of the Rare Earth Metals at Low Temperatures* "
DR. J. M. LOCK
At Royal School of Mines, at 4 p.m.

Feb. 20 — Colour Group
" *Goethe's Experiments on Colour* "
MR. M. H. WILSON
" *Trichromatic Ideas in the Seventeenth and Eighteenth Centuries* "
DR. R. A. WEALE
At the Institute of Ophthalmology, at 3.30 p.m.

March 7 — Optical Group. At Imperial College, at 2.30 p.m.
Annual General Meeting followed by
" *An Intensity Interferometer, and the Measurements of Stellar Diameters* "
MR. R. HANBURY BROWN
" *The Statistics of Beams of Light* "
DR. F. D. KAHN

The Institute's Journals

PRINCIPAL CONTENTS OF THE FEBRUARY, 1957, ISSUES

Journal of Scientific Instruments: Volume 34, No. 2

SPECIAL ARTICLE

An introduction to the study of non-linear control systems. By J. F. Coales, F.Inst.P. (*Department of Engineering, University of Cambridge*).

Non-linearity is explained and defined by deriving the law of superposition for linear systems and showing that it does not apply to non-linear systems. Non-linearities are inevitable in many control system components but in some cases a virtue can be made of necessity and the performance of a system improved by the use of non-linear damping and in some cases of non-linear gain. The position of non-linearity in the system is important and any general analysis of a non-linear system is exceedingly difficult unless the non-linearity occurs in the forward loop immediately before the load.

Various authors have suggested methods of classification of non-linearities but as yet no generally satisfactory system is available. Various methods of analysis have been worked out but only for low order systems with determinate inputs. These are quite successful but as yet no general method has been developed for the analysis of systems with random inputs.

ORIGINAL CONTRIBUTIONS

A sensitive photoelectric polarimeter. By B. R. Malcolm, A.Inst.P., and A. Elliott (*Courtaulds Ltd., Maidenhead, Berks*).

The construction of a simple photoelectric polarimeter is described. The instrument has a sensitivity considerably higher than the usual visual type but with a more restricted range. Features of the instrument which make for convenience in operation and also to which attention must be paid in order to use fully the intrinsic sensitivity of system are outlined.

A precision paramagnetic resonance spectrometer. By K. D. Bowers, R. A. Kamper and R. B. D. Knight, Grad.Inst.P. (*Clarendon Laboratory, University of Oxford*).

An instrument is described for the accurate comparison in the same magnetic field of the frequency of electronic magnetic resonance absorption, particularly in gaseous materials, with the frequency of proton resonance absorption. Details are given of (1) the production of a homogeneous magnetic field, which can be stabilized at any value between 1 and 11 kG ; (2) the production and measurement of the radio-frequencies used for the observation of proton resonance in this field ; (3) the supply and measurement of a stable microwave frequency in the region of 9,000 to 10,000 mc/s ; (4) the sensitive detection of paramagnetic resonance absorption at this frequency using 115 kc/s magnetic field modulation. The precision of the measurements is about three parts per million ; it is limited mainly by the homogeneity of the magnetic field, and the measurement of the proton resonance frequency.

A variable structure-factor graph for use in crystal-structure determination. By K. A. Morley and C. A. Taylor, F.Inst.P. (*Physics Department, College of Technology, Manchester*).

The instrument incorporates two tables, linked so that a rotation of one causes an identical rotation of the other. A drawing of proposed atomic positions is placed on one table and lies under a net of parallel wires which represent the contours of a structure-factor graph.(4) The spacings of these wires and the relative orientation of the drawing may be adjusted to correspond with any given point on a representation of the diffraction pattern placed on the second table. Suggestions may then be obtained, from the relative disposition of atomic positions and contour lines, for changes that would improve the agreement between the diffraction patterns of the proposed and actual structures. The instrument has already given useful assistance in a number of problems.

Although it is introduced from the standpoint of optical transforms, the instrument could equally well be used with conventional computational methods. Also, since it is virtually a one-dimensional Fourier transformer, it may find applications in other fields.

A thermistor device as automatic gain control in lamp-photocell transducer systems. By A. M. Hardie (*Robert Gordon's Technical College, Aberdeen*).

This paper describes the design of a regulator using thermistors to compensate for the slow drift of illumination from a lamp source and changes in photocell characteristics which normally affect the calibration accuracy of vibration equipment when a photoelectric transducer is employed. The regulator operates by

stabilizing the mean component of the modulated voltage across the photocell load resistance itself, comprising one or more series-connected thermistors of the indirectly heated type. Design details are given of a regulator which stabilizes the system to within 0.03% when the light beam is symmetrically modulated by the vibration under study.

A small vacuum induction furnace. By J. C. Matthews (*Physics Department, University of Leeds*).

Melts on a laboratory scale, up to 300 g, may be made under high vacuum. Material may be added to the crucible from a hopper and the melt cast into a split copper mould while under high vacuum. The furnace is used in conjunction with a high-voltage, high-frequency generator, and although intense ionization occurs this does not affect the functioning of the furnace.

An improved inductance method for measuring susceptibilities of small paramagnetic specimens at low temperatures. By F. R. McKim and W. P. Wolf (*Clarendon Laboratory, University of Oxford*).

An apparatus is described with which the susceptibilities of small paramagnetic specimens can be determined at temperatures between 77 and 1·8°K. The measurements are made in terms of the change of mutual inductance produced by moving a specimen inside a coil system, using a Hartshorn bridge operating at 175 c/s to measure the inductance. The chief advantage of this type of apparatus is its simplicity of operation, since it involves no delicate moving parts. The sensitivity and reproducibility of the apparatus were investigated using a specimen of manganous ammonium sulphate and it was found that susceptibilities of the order of 3×10^{-6} c.g.s. units could be measured to an accuracy of 1%. Sources of error are discussed.

A 100 kV compressed-gas standard capacitor. By T. R. Foord (*Dept. of Electrical Engineering, University of Glasgow*).

The construction of a reference standard capacitor of value 99·2 pF having nitrogen at 120 lb/in.² as dielectric and suitable for use at voltages up to 100 kV (r.m.s.) is described.

The method of measurement of the interelectrode capacitance and the effect of eccentricity of the cylindrical electrodes are also considered.

LABORATORY AND WORKSHOP NOTES.

NOTES AND NEWS

NOTES AND COMMENTS

British Journal of Applied Physics: Volume 8, No. 2

SPECIAL ARTICLE

Some applications of physics to wood. By R. F. S. Hearmon, F.Inst.P. (*Forest Products Research Laboratory, Princes Risborough, Aylesbury, Buckinghamshire*).

A review is given of some of the more important physical properties of wood, particularly the hygroscopic, thermal, electrical and elastic properties. The vibration behaviour is also considered, with special reference to the effect of shear and rotatory inertia in flexural vibration and to the connexion between frequency of vibration and elastic stability.

ORIGINAL CONTRIBUTIONS

The standardization of X-ray output in industrial radiology. By R. S. Morgan, A.Inst.P., R. Halmshaw, A.Inst.P., and B. J. Ratcliffe (*Armament Research and Development Establishment, Woolwich, London*).

Variations in the output of radiation from different X-ray sets, when operated at the same nominal scale voltage, have been shown to be attributable to differences in the effective applied voltage. Such variations of output lead to difficulties in the standardization of radiographic techniques. More accurate calibration of the effective applied voltage has been shown to be required and it is suggested that considerable improvement could be obtained by calibrating the output of X-ray sets in terms of roentgens per minute and specifying exposures in roentgens.

A millisecond relaxation process in the reverse current of germanium point-contact diodes. By R. E. Burgess (*Radio Research Station, Slough, Bucks*).

When a reverse voltage is suddenly applied to a germanium point-contact diode initially having zero bias it has been found that there is usually a decrease of current to the final steady value with a relaxation time of about 1 ms. Possible mechanisms for this process are discussed, and it is suggested that redistribution of surface charge is the most likely cause.

The fundamental modes of vibration of uniform beams for medium wavelengths.

By G. J. Kynch (*Department of Applied Mathematics, University College of Wales, Aberystwyth*).

The Rayleigh-Ritz method is used to determine approximate forms for the dispersion curves of a vibrating infinite beam of arbitrary shape, using the exact elasticity equations. The method is also used to investigate the relations between the different types of vibration. The results for flexural vibrations confirm the Timoshenko equation for most beams and include corrections for thin strips. Dispersion curves are obtained for longitudinal-type vibration which shows the variation with shape and the change in classification of the modes when the symmetry of the cross-section is altered. When the wavelength is of the order of magnitude of the perimeter, the usual longitudinal mode is replaced as the fundamental mode by a new mode.

Pre-breakdown conduction between electrodes in continuously pumped vacuum systems. By W. K. Mansfield, A.Inst.P., and R. L. Fortescue (*Nuclear Particle Laboratory, Queen Mary College, University of London*).

Electron loading in electrostatic generator accelerator tubes due to the passage of pulses of current of millisecond duration has been investigated. The characteristics of pulse discharge conduction are described and a theory of its origin proposed. This theory envisages an exchange of positive and negative ions of hydrogen between the electrodes in a regenerative reaction, the source of the ions being a chemi-sorbed layer of hydro-carbon on the electrode surfaces. Measurements of the secondary emission coefficients and other experimental evidence appear to be consistent with such a hypothesis. Methods of suppression of this pulse discharge conduction are discussed.

Application of a microfocus Laue technique to the study of deformation in aluminium single crystals. By R. A. Coyle, A. M. Marshall, Grad.Inst.P., J. H. Auld and N. A. McKinnon (*Aeronautical Research Laboratories, Department of Supply, Commonwealth of Australia, Melbourne*).

A microfocus Laue technique is applied to deformed single crystals ; the criterion for resolution is discussed and a description is given of an indexing net and a method of measuring image distortions and magnifications. Images of kink bands and bands of secondary slip are shown and the formation of kink bands by rotation about a [211] axis is confirmed. Kink band images are shown to be caused by overlapping images and not extinction effects at the low amounts of strain (1%) used.

The lives of electron microscope filaments. By R. N. Bloomer, A.Inst.P. (*Associated Electrical Industries Ltd., Aldermaston, Berks*).

The lives of the tungsten filaments used in electron microscopes can be limited by the thermal evaporation of the metal, or by chemical attack, in inferior vacua. The lives to be expected when either cause is dominant are calculated for a variety of operating conditions. Comparison of these calculated values with measured lives shows that thermal evaporation limits lives in microscopes used at high magnifications. The life limited by evaporation decreases as the temperature and thermionic emission increase, and so corresponding values of filament life and ideal gun output brightness (thermionic emission density per unit solid angle) have been calculated for normal working temperatures, in order that a compromise may be made.

NOTES AND NEWS

NEW BOOKS

NOTES AND COMMENTS

HAMMERSMITH HOSPITAL AND POSTGRADUATE MEDICAL SCHOOL
DU CANE ROAD, LONDON, W.12.
PHYSICIST (Senior Grade)

required for Physics Department for work in physics applied to radiotherapy and radiodiagnosis. Some postgraduate teaching to D.M.R. students. Experience in radiation physics and hospital X-ray equipment essential. Salary scale £910–£1,230 plus London Weighting.
Age, qualifications, experience, names of two referees to Secretary Board of Governors by February 23.

UNITED KINGDOM ATOMIC ENERGY AUTHORITY
ENGINEERS, CHEMISTS AND PHYSICISTS

Applications are invited by the Industrial Group of the United Kingdom Atomic Energy Authority for vacancies in the Commercial and Overseas Departments of the Technical Policy Branch at Risley, Warrington, Lancs.
A. Commercial Department (Reference No. 1745)
The duties will be concerned with the exploitation of technological information and sales of materials, particularly nuclear fuel, by the Authority, both in the United Kingdom and Overseas. There will also be opportunities for working in collaboration with British Industry and the Electricity Supply Authorities in the development of industrial applications of atomic energy.
A sound technical/commercial background is called for with the ability to appreciate the commercial value of technological development work. Candidates should have had previous experience of (*a*) high level industrial negotiations and the drawing up of commercial agreements and/or sales contracts, and/or (*b*) working in close liaison with the Research Engineering and Production Departments of a major industrial concern.
Selected candidates will be given facilities to acquire an understanding of the technical processes and plants of the Industrial Group.
B. Overseas Department (Reference No. 1747)
The responsibilities will cover a wide range of duties including negotiations with foreign government departments and industrial concerns ; the implementation of international agreements on the peaceful use of atomic energy and attendance at international conferences. In the technical field all aspects of atomic power generation will be covered, including design and construction of power reactors and chemical plants, together with design and fabrication of fuel elements.
Preference will be given to candidates in their early thirties with a background of technical achievement and ability to appreciate detail rapidly. Previous experience of overseas liaison and a knowledge of economics will be an advantage.
Qualifications :—
Candidates for all posts should possess a degree in one of the applied sciences and/or be corporate members of one of the senior professional institutions.
Salaries will be assessed within the following scales :—
Grade I : £1,705–£1,980 per annum
Grade II : £1,235–£1,655 per annum.
A contributory pension scheme is in operation.
Authority houses for renting by successful married candidates may be available in due course, or alternatively, substantial assistance may be given towards legal expenses incurred in private purchase.
Send a postcard asking for an application form and quoting appropriate reference number to The Recruitment Officer, United Kingdom Atomic Energy Authority, Industrial Group Headquarters, Risley, Warrington, Lancs.
Closing date—March 4, 1957.

A new British Company
TEXAS INSTRUMENTS LTD.
Applications are invited from
PHYSICISTS, CHEMISTS, METALLURGISTS
and ELECTRICAL or MECHANICAL ENGINEERS
with previous experience in
SEMICONDUCTORS

for various attractive positions with this new British Company which will manufacture transistors on a large scale. The Company's factory will be at Bedford.
Applicants should submit a short résumé of their career stating, in particular, their age, qualifications and experience in semiconductors. They should also state their preference for research, development, production, applications or sales, and salary required. This is an exceptional opportunity for young men with energy and initiative, aged approximately 25–35, to join at its outset an important new Company in this rapidly expanding industry.
Apply to John Haddon & Co. Ltd., 11–12 Salisbury Square, London, E.C.4.

THE INSTITUTE OF PHYSICS
SCOTTISH BRANCH AND EDUCATION GROUP

A SCOTTISH CONFERENCE ON TRAINING IN PHYSICS

will be held on Friday and Saturday, April 12-13, at the Royal College of Science and Technology, Glasgow.

Speakers include : Professor W. H. J. Childs, F.Inst.P., Dr. R. A. Smith, Professor P. I. Dee, F.Inst.P., F.R.S., Professor H. Lipson, F.Inst.P., Dr. G. Morris, F.Inst.P., Mr. A. L. Chilcot, Mr. J. C. Young, Mr. D. McGill and Mr. W. S. Gray.

Further details and forms of application may be obtained from Dr. A. R. Boyle, A.Inst.P., Dobbie McInnes Ltd., 55 Kelvin Avenue, Glasgow, S.W.2, or from the Deputy Secretary of the Institute.

THE GAS COUNCIL MIDLANDS RESEARCH STATION

Applications are invited from suitably qualified CHEMISTS, PHYSICISTS, CHEMICAL ENGINEERS AND FUEL TECHNOLOGISTS

for appointments in this newly established research station, which is concerned with novel methods of gas manufacture and with improving the use of gas, especially in industry.

Candidates should hold, at least, a Second Class honours degree of a British university, or an equivalent qualification and be free of National Service liabilities. Postgraduate research experience is an advantage.

Men and women who after experience show the qualities of effective leadership of investigations will be paid salaries commensurate with these attributes. The Station is in Solihull in Warwickshire and is within easy reach of Birmingham.

Applications in writing, detailing education, qualifications and experience, should be sent to the Industrial Relations Officer, West Midlands Gas Board, 6 Augustus Road, Edgbaston, Birmingham, 15.

J. C. Ingram,
Secretary to the Board.

BRITISH CELLOPHANE LTD. have vacancies for honours degree physicists interested in production technology, and with the ability to assume responsible posts later. Applicants are invited to submit in confidence full details of their qualifications and experience. Initial work will comprise plant-scale investigations into production problems. Adequate salaries to the right men. Please quote ref. no. M21.IP.

Application forms may be obtained from the Personnel Officer, British Cellophane Ltd., Bath Road, Bridgwater, Somerset.

SITUATIONS VACANT

BRITISH ENKA LIMITED

Producers of Man-Made Fibres

Physicists and Physical Chemists are required in the Research Department based on newly constructed, well-equipped laboratories. Both physicists and physical chemists should have good honours or research degrees and physicists will be required to deal with experimental problems in the field of classical physics. These posts offer permanent, progressive opportunities with good salaries and pension scheme for suitable applicants. Applications, which will be treated in confidence, should state age, qualifications, experience in chronological order, present remuneration and be addressed to :

Personnel Manager
BRITISH ENKA LTD.
Aintree, Liverpool, 9

IMPERIAL CHEMICAL INDUSTRIES LIMITED

Dyestuffs Division
have a vacancy in their
RESEARCH LABORATORIES
for a

PHYSICIST

to undertake the development of new methods of mass-spectrometry. The work will involve the design and construction of special apparatus and, later, its application to investigations of a non-routine nature. Applicants should hold a good Honours degree in physics, possess some experience of electronics and preferably have an interest in chemical physics. Salary will be in accordance with qualifications and experience. Profit sharing and pension schemes are in operation, and, in appropriate cases, assistance can be given with housing. Write to the Staff Manager, Imperial Chemical Industries Limited, Dyestuffs Division, Hexagon House, Blackley, Manchester, 9, giving very brief details of age, experience and qualifications. Please quote Ref. I.63/Phys.

ATOMIC ENERGY RESEARCH ESTABLISHMENT
HARWELL

The Research Programme is being extended and there is a large number of vacancies in the Metallurgy Division for good Honours graduates in physics, chemistry and metallurgy to initiate and direct research in the following fields :

BERYLLIUM : research on the fabrication of beryllium and its alloys and their application in power reactors. Industrial or research experience advantageous.

PLUTONIUM : research on and development of plutonium and its alloys. Requires ability to break new ground and a flair for novel experimental methods in dry boxes.

SOLID STATE PHYSICS : largely academic work using neutron beams and involving the operation of neutron spectrometers at the research reactors.

LIQUID METAL FUELS : fundamental and applied work on the study of metallic solutions, slurries and compounds under inactive and irradiated conditions in the development of liquid metal fuels for power reactors.

Send a postcard (for further details and application form), which must be returned by February 22, to the Establishment Officer, A.E.R.E., Harwell, Didcot, Berks, quoting reference 700/110.

Vacancies for

PHYSICISTS

THESE APPOINTMENTS CARRY SALARIES UP TO £1,450 p.a.

THERE ARE GOOD OPPORTUNITIES FOR MEN OF ABILITY TO ADVANCE TO POSITIONS CARRYING SALARIES OF THE ORDER OF £2,000 p.a.

A variety of research work in basic and applied physics is being carried out in our Research Department, and there are also vacancies for men interested in plant work as Instrument Managers. If you are interested and you hold a good honours degree, we shall be pleased to hear from you. Applications are invited from men with experience in research or industry, and also from those who have just completed their degree course. Where necessary appropriate training will be arranged by the company. Write, giving brief details of age, qualifications and experience, to The Staff Manager, Imperial Chemical Industries Ltd., Billingham Division, Billingham, Co. Durham, quoting reference b-w-4.

THE G.E.C. is establishing a Development Laboratory at its Lamp Division near Manchester, which manufactures tungsten filament lamps, discharge lamps and electrical discharge devices. The laboratory will study new methods of manufacture, and the potentialities of new light sources. This group will work in close collaboration with the Company's central research laboratories at Wembley. Applications are invited from those interested in experimental work in the high vacuum and light engineering fields. Vacancies exist for male and female applicants in the following categories :—

(1) Physics graduates (honours level in physics).
(2) Holders of H.N.C. in mechanical or electrical engineering.
(3) Technical Assistants with O.N.C. in mechanical or electrical engineering.
(4) Student Assistants with G.C.E. in four subjects.
(5) Technical Operators (female).

The Company operates a pension scheme and a five-day week. Canteen and social club facilities are available.
Apply in writing giving full details of age, education and experience to the Personnel Officer, Osram Lamp Works, Cape Mill, Refuge Street, Shaw.

PHYSICIST or X-RAY CRYSTALLOGRAPHER with postgraduate research experience required for fundamental research group in North London Laboratories. Experience in metallurgy desirable but not essential. Attractive salary according to age and experience. Apply in writing to Research Manager, Murex Welding Processes Ltd., Waltham Cross, Herts.

Applications are invited for the post of Physicist to be concerned with dosimetry and physical investigations arising in therapy with X-rays and radioactive sources. Equipment at present in use includes rotation therapy apparatus, a 2 meV. Van de Graaf generator, 10 curie radium and cobalt units and a 1,300 curie caesium unit. The appointment will be in Scientific Grade I, on the scale £1,270 × £50–£1,470 with superannuation and child allowances. Applications giving details of qualifications and experience and the names of three referees, should be sent to the Secretary, Institute of Cancer Research, Royal Cancer Hospital, Fulham Road, S.W.3, as soon as possible.

AERODYNAMICIST, DEVELOPMENT ENGINEERS, PHYSICISTS

both senior and junior are required by Louis Newmark Ltd., for their expanding laboratories at New Addington, Surrey, for work on aircraft control systems. The work involved covers all aspects of the overall design, development and flight testing of autopilots and autostabilizers for fixed and rotary-wing aircraft. In addition there are vacancies for more specialized work on gyroscopes, accelerometers, capsule and servo follow-up instruments for incorporation in these systems.
Applicants for the more senior positions should preferably have a degree or equivalent qualifications, and for all the vacancies some experience in the above fields or on small electro mechanical instruments is an advantage. Applications from suitable ex R.A.F. technical personnel are welcomed. Pension Scheme. Apply in writing to the Personnel Officer, Louis Newmark Ltd., Purley Way, Croydon.

ENGINEERS AND PHYSICISTS

are required

in the Atomic Power Division

Research and Development Department

of English Electric Co. Ltd.,

Whetstone, Near Leicester

This department deals with chemical and electrical problems in connexion with

The National Atomic Power Programme

Previous experience not essential. The Company can offer successful applicants housing assistance and a good pension scheme. Please write to Dept. C.P.S., 336/7 Strand, W.C.2, quoting Ref. PB 1800G.

NUCLEAR PROJECTS GROUP

A small but expanding design team has been established in the West End of London. Applications are invited from qualified men aged 24–28 years to fill the following positions :

(1) **Mathematical Physicist to carry out nuclear calculations on reactor core and shield.**

(2) **Applied Mathematician to investigate control problems. Knowledge of servo-mechanism theory desirable.**

Proposed salaries are up to £1,000 per year dependent upon qualifications, age and experience, and successful applicants will be afforded the opportunity of attending the Reactor School at Harwell.

Particulars of qualifications, age, experience, etc., should be forwarded to :

The Personnel Officer
The de Havilland Engine Company Ltd.
Stag Lane, Edgware, Middlesex

NON-DESTRUCTIVE TESTING TECHNIQUES

Attractive and responsible positions are offered in the development of new techniques for the non-destructive examination of materials.

Senior and junior staff are required with qualifications or experience in the fields of physics or physical metallurgy with particular reference to the non-destructive examination of materials or industrial instrumentation and measurement. Salaries commensurate with qualifications and experience will be paid.

Application should be made in writing in the first instance giving full details of qualifications, previous experience, age and salary required, and be addressed to : Personnel Department, Kelvin & Hughes Ltd., New North Road, Barkingside, Essex.

PHYSICIST

The National Research Council of Canada has an immediate vacancy at their Ottawa laboratories for a Physicist or Chemical Physicist with a Ph.D. degree to collaborate in a small expanding group which is studying dielectric relaxation effects at all frequencies from d.c. to 300 kMc/s (1mm). The position offers a well-equipped laboratory with unusual freedom of work and publication. Initial salary up to $6,500 per annum depending on qualifications. Staff benefits include a superannuation plan, five-day week, and generous holidays and sick leave. Applications giving full details of education and experience, age, etc., should be sent to the Employment Officer, National Research Council, Sussex Drive, Ottawa 2, Canada. Please quote file AP101.

COMMONWEALTH OF AUSTRALIA

COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION

DIVISION OF TRIBOPHYSICS—APPOINTMENT NO. 370/111 OF RESEARCH PHYSICIST

The Division of Tribophysics, located at the University of Melbourne, invites applications from physicists to work with its solid state group on problems requiring the techniques of nuclear magnetic resonance. This group is studying lattice defects and the mechanism of plastic deformation.

Applicants should possess a University honours degree in physics or equivalent qualifications and preferably with research experience to at least Ph.D. standard. According to qualifications and experience commencing salary will be determined within the salary range of Research Officer £A1,287–£A1,912 p.a.

The appointment, which will initially be for a period of three years, will be conditional on a satisfactory medical examination.

First-class sea fares to Australia will be paid for the appointee, his wife and family. Return fares will also be paid if the appointment is not extended.

Applications, referring to Appointment No. 370/111, and stating full name, place, date and year of birth, marital state, particulars of qualifications and experience and of war service, if any, accompanied by copies of not more than four testimonials, and the names and addresses of at least two persons willing to act as referees if required, should reach the undersigned, from whom further particulars may be obtained, by March 15, 1957.

A. Shavitsky,
Chief Scientific Liaison Officer
Australian Scientific Liaison Office,
Africa House,
Kingsway,
London, W.C.2.

NON-DESTRUCTIVE TESTING TECHNIQUES

Two attractive positions are offered which will involve hard work and extensive travelling in the United Kingdom and Europe. The successful applicants will be concerned with the development and industrial application of modern non-destructive testing techniques. They must have the following qualifications:

1. Initiative
2. Experience in the industrial application of modern electronic techniques and/or mechanical design. It is desirable that they should also have adequate academic qualifications.
3. Age 23 to 30 years.
4. Salaries will commensurate with the candidate's qualifications and experience.

Application should be made in writing in the first instance giving full details of qualifications, previous experience, age and salary required, and be addressed to : Personnel Department, Kelvin & Hughes Ltd., New North Road, Barkingside, Essex.

Chartered Patent Agents

W. H. BECK, GREENER & CO.

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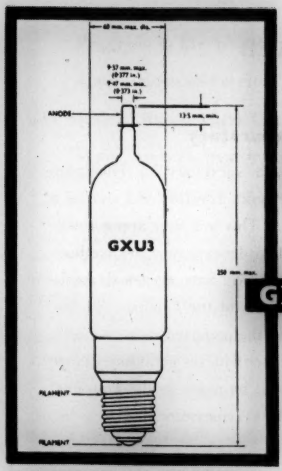


G.E.C.

xenon rectifiers

In certain applications, Xenon rectifiers are preferable to mercury rectifiers.

Advantages
1. Greater ambient operating temperature range (—55 to +170°c)
2. Shorter switching delay
3. Better storage properties

GXU 3

This valve can be used as a replacement for such valves as the C.V.5. and G.U. 20/21

FILAMENT		
Vf	4.0	V
If	11.0 (approx.)	A

RATING.	All values are absolute	
PIV	13 max.	kV
Ik (pk)	6 max.	A
Ik (av)	1.25 max.	A
Ik (surge)	60 max.	A

Also available are:—

GXU 2 This valve is equivalent to the 4B32 and CV2518

FILAMENT		
Vf	5.0	V
If	7.1 (approx.)	A

RATING.	All values are absolute	
PIV	10 max.	kV
Ik (pk)	5.0 max.	A
Ik (av)	1.25 max.	A
Ik (surge)	50 max.	A

GXU 4 This valve is similar to the GXU 3, but has a 4V.7A heater.

NOTE: A special feature of the GXU2, GXU3 and GXU4 valves is an enclosed anode design which results in an improved life.

Full particulars of these valves can be obtained from the G.E.C. VALVE & ELECTRONICS DEPT.

THE GENERAL ELECTRIC CO. LTD., MAGNET HOUSE, KINGSWAY, W.C.2

Appointments Vacant

The inclusion of particulars of a vacancy must not be taken to imply that the Institute necessarily approves of the terms offered or that might be offered. Candidates should satisfy themselves that these are satisfactory, and they may always refer to the Institute for advice.

THE BRITISH COTTON INDUSTRY RESEARCH ASSOCIATION
(SHIRLEY INSTITUTE)

Physicist or Engineer. A vacancy exists for a young physicist or engineer, to work on physical problems associated with the development of automation in the textile industry. The work is interesting and varied, and concerned initially with the design and application of automatic control systems and with mechanical handling. Candidates should be capable of a fundamental approach to these problems but should have an interest in applying the results in practice. The post offers a progressive scientific career at the Institute, and the initial salary will be in the range £600—£900. The post carries with it participation in the Federated Superannuation System for Universities. Applications, giving full particulars of qualifications and careers, should be sent to: Dr. D. W. Hill, Director of Research, Shirley Institute, Manchester, 20.

ASSISTANTSHIP IN RESEARCH
IN THE DEPARTMENT OF ENGINEERING
CAMBRIDGE UNIVERSITY

The Faculty Board of Engineering wish to appoint as soon as possible, an Assistant in Research in the Department of Engineering. The successful candidate will be expected to work on theoretical aspects of non-linear control systems (automatic controls and servomechanisms) and the duties will include numerical analysis both by hand and by means of electronic digital and analogue computing machines.

Applicants should have a University degree in Engineering, Physics or Mathematics but preference will be given to those with an honours degree in mathematics.

Application should be made not later than March 31, 1957, to the Secretary of the Department of Engineering, Engineering Laboratory, Trumpington Street, Cambridge, from whom further particulars may be obtained.

ASHDOWNS LIMITED
ST. HELENS

Head of Plastics Test Laboratory

ASHDOWNS LIMITED (Plastic Manufacturers), a subsidiary of Pilkington Brothers Limited, require an Honours Graduate in Physics to set-up and control a test laboratory for raw materials and finished goods. This is a new appointment and calls for an able and enthusiastic man prepared to develop new test methods as well as to review current procedure. The laboratory will have electrical, mechanical and chemical test sections to deal with all aspects of the Company's work. Applications from all age groups will be welcomed, but the preferred range is 27-33. Salary will be fixed by agreement and will be in accordance with the great importance which is attached to this situation. Applications should be made to the Personnel Liaison Officer, Pilkington Brothers Limited, St. Helens, Lancashire.

MATHEMATICIANS
required by
ATOMIC WEAPONS RESEARCH ESTABLISHMENT,
ALDERMASTON, BERKS
in the grade of

Senior Experimental, Experimental and Assistant Experimental Officers to assist mathematical Physicists in the study of basic physical phenomena occurring in atomic explosions. The duties will include preparation of numerical problems for electronic computers and interpretation of results.

The minimum qualification is H.S.C. with maths. as a principal subject, or G.C.E. in five subjects, including maths. and one other subject at Advanced Level, but preference will be given to University Graduates.

Candidates for the Experimental Officer posts should be at least 26 years of age and should normally be 35 years of age for the Senior Experimental Officer posts.

Salary :—

Senior Experimental Officer : £1,295—£1,550 p.a. (male).
Experimental Officer : £940—£1,155 p.a. (male).
Assistant Experimental Officer £375 (age 18)—£665 (age 26 or over)—£815 p.a. (male).

Contributory Superannuation Scheme. A house, or assistance towards legal expenses on house purchase, will be available for married officers living beyond daily travelling distance. Postcard for application forms to Senior Recruitment Officer at the above address. Please quote 1436/110.

BRITISH CELLOPHANE LTD. have vacancies for honours degree physicists interested in production technology, and with the ability to assume responsible posts later. Applicants are invited to submit in confidence full details of their qualifications and experience. Initial work will comprise plant-scale investigations into production problems. Adequate salaries to the right men. Please quote ref. no. M21.IP.

Application forms may be obtained from the Personnel Officer, British Cellophane Ltd., Bath Road, Bridgwater, Somerset.

UNIVERSITY OF GLASGOW
LECTURESHIPS IN EXPERIMENTAL PHYSICS

Applications are invited for Lectureships in Experimental Physics. Salary scale : Lecturer : £650 × £50—£1,350 ; Senior Lecturer : £1,400 × £50—£1,650. Grade of appointment and initial salary according to experience and qualifications. F.S.S.U. and family allowance benefits. Successful applicant will be expected to prosecute experimental research in Nuclear Physics in addition to teaching duties.

Applications (five copies), including the names of two referees, should be lodged not later than March 30, 1957, with the undersigned from whom further particulars may be obtained.

Robt. T. Hutcheson,
Secretary of University Court

Progress in Electronics

Applications of Ferrites

The Mullard Radio Valve Co. Ltd.,

in this new field, requires a

PHYSICIST

with a sound knowledge of electronics, circuitry and test gear for a responsible post in connexion with the testing and application of ferrite materials and components.

The work will be mainly concerned with more recent fields of application of ferrites, for which new materials are being developed and for which specialized techniques are being devised for the measurement of magnetic properties.

The post is tenable at the Mitcham factory within easy distance of London and is expected to provide considerable opportunities for the successful candidate.

The commencing salary will be according to the qualifications and experience of the successful applicant and can be regarded as senior level.

The Company operates a long service holiday and pension plan and a feature of employment is the opportunity to assume early responsibility within the field of work.

The post requires a working week of 44 hours, 5 days per week.

Applications should be made in writing to :

The Personnel Officer,

THE MULLARD RADIO VALVE Co. Ltd.

New Road, Mitcham Junction, Surrey,

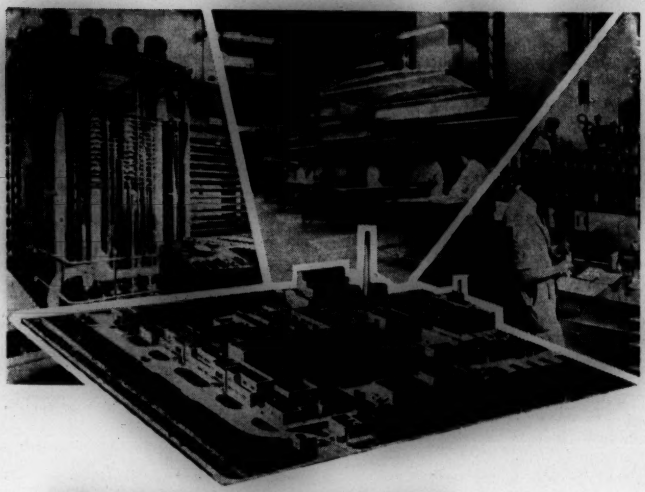
quoting Reference JFG/SI

HIVAC LTD., a Company associated with a major Group in the telecommunications field, requires scientific and technical staff to work on the development and production of valves, cold cathode tubes and transistors. Applications are invited from PHYSICISTS, CHEMISTS and ENGINEERS, having a degree or equivalent qualification and interested in these fields. Previous experience is not essential but would be an advantage for the more senior appointments, for which the ability to work with the minimum supervision is required. The posts are pensionable and offer considerable scope for advancement and vacancies are available at both Harrow-on-the-Hill and South Ruislip.
Applications, which will be treated in strict confidence, should be addressed to The Engineer-in-Chief, Hivac Ltd., Stonefield Way, Victoria Road, South Ruislip.

A vacancy exists in new and growing Research Laboratories near Cambridge for an Electron Microscopist to assist research scientists working on a variety of physical, metallurgical and chemical problems and to maintain and operate Siemens and Metropolitan-Vickers microscopes, diffraction camera and X-ray projection microscopes. Excellent working conditions. Canteen. Free transport to and from Cambridge and Saffron Walden. For application forms please apply to The Secretary, Tube Investments Research Laboratories, Hinxton Hall, near Saffron Walden, Essex. Quoting reference 132.

EXPERIMENTAL OFFICER required by the Atomic Weapons Research Establishment, Aldermaston, Berks, for duty at Orfordness, Suffolk, to carry out experiments designed to investigate the mechanical strength of complex assemblies ; to instrument parts for experiments and to analyse experimental results. Minimum qualification of H.N.C. (Eng. or Applied Physics) but pass degree an advantage. Candidates, who should be over 26 years of age, should have had good practical training in either of these subjects and must be prepared to work unusual hours. Previous research and development experience in mechanical engineering and of the recording of strain, displacement and acceleration by oscilloscope an advantage.
Salary £940—£1,155 p.a. (male). Contributory superannuation scheme. A house or assistance towards legal expenses on house purchase will be available for married officers living beyond daily travelling distance. Postcards for application forms to the Senior Recruitment Officer at A.W.R.E., Aldermaston. Please quote ref. 1432/110.

CITY OF LEEDS EDUCATION COMMITTEE
LEEDS COLLEGE OF TECHNOLOGY
COOKRIDGE STREET, LEEDS, 2
Principal : C. Chew, M.Sc.Tech., F.R.I.C.
Assistant Lecturer Grade B in physics (man or woman) required. Applicants should have a good degree or equivalent qualification, have had industrial experience and preferably teaching experience also.
Burnham salary scales £650 × £25—£1,025 plus £75 for degree or £125 for good honours degree ; woman £580 × £20—£820 plus £60 for degree or £100 for good honours degree and equal pay increments. Full allowance for training and experience. For further particulars and form of application send stamped addressed foolscap envelope to the Principal of the College. Closing date March 18.
Education Department, Leeds, 1.
George Taylor, Chief Education Officer



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